

HYDROLOGIC KNOWLEDGE IN ANCIENT INDIA

[Second Edition]



National Institute of Hydrology
(Ministry of Water Resources, River Development and Ganga Rejuvenation)
Jal Vigyan Bhawan
Roorkee-247 667 (Uttarakhand), India

December, 2018

Shlokas for Invoking River Goddess

गंगे च यमुने चैव गोदावरि सरस्वति ।

नर्मदे सिंधु कावेरि जलेऽस्मिन् सन्निधिं कुरु ॥ Sri Bruhannardiya Puran

Meaning: O rivers Ganga, Yamuna, Godavari, Saraswati, Narmada, Sindhu and Kaveri, please enrich the water I am bathing with, with your presence.

गंगा सिंधु सरस्वति च यमुना गोदावरि नर्मदा ।

कावेरि शरयू महेन्द्रतनया चर्मण्वती वेदिका ॥

क्षिप्रा वेत्रवती महासुरनदी ख्याता जया गण्डकी ।

पूर्णाः पूर्णजलैः समुद्रसहिताः कुर्वन्तु मे मंगलम् ॥

Meaning: May rivers Ganga, Sindhu, Saraswati, Yamuna, Godavari, Narmada, Kaveri, Sharyu, Mahendratanaaya, Chambala, Vedika, Kshipra, Vetravati (a rivulet), chiefly the Mahasurnadi, Jaya and Gandaki become sacred and absolute, and along with the sea, shower benevolence on me.

नमामि गंगे तव पादपंकजं सुरासुरैर्वन्दितदिव्यरूपाम् ।

भुक्तिं च मुक्तिं च ददासि नित्यं भावानुसारेण सदा नराणाम् ।

Meaning: O Mother Ganga, the bestower of all worldly happiness, pleasures and Moksha as per the different levels of bhav of the worshipper, all Deities and demons worship your Holy feet, I too offer obeisance at your Holy feet.


Preface to the Second Edition

For human beings, water is not merely a substance that sustains life. Water management is an elemental ingredient in the way people conceive the world and an expression of their thoughts and emotions. Hydrologic knowledge in India has a historical footprint of several millenniums. As in many ancient civilisations across the world, the need to manage and use water drove the growth of hydrology in ancient India also. Evidences from ancient history provide an insight into the hydrological knowledge generated by Indians more than 5000 years ago. What is less known, however, is the rigorous discussion on several aspects of hydrologic processes in the ancient Indian scriptures as we understand them today.

This report reveals that the knowledge of hydrology was pervasive in ancient India starting from pre- Indus Valley Civilization days and has been discussed in-depth in Vedas, Puranas, Arthasastra, Astadhyayi, Vrhata Samhita, Ramayana, Mahabharat, Meghmala, Mayurchitraka, Jain and Buddhist and many other ancient literatures. However, it had remained unearthed and unexplored in front of the world at large till the recent times. This report, like its predecessor, is a sincere effort to present the ancient Indian hydrologic knowledge to the Indian and the world community. The report has a special importance, particularly in an era of population growth, environmental degradation and climate change leading to increasing hydrological extremes and stresses. The climate change phenomenon would also have greater impacts on water and food security. At the same time, the competition among various water sectors is increasing and thus requiring a larger emphasis on water resources management to achieve the goals of sustainable development (SDGs). The ancient water technologies discussed in this book should be considered not merely as historical artefacts, but as potential tools for sustainable water technologies for the present and the future.

While updating the report, a number of recent national as well as international research papers and technical book published by various national and international institutions have been referred. Figures illustrating various concepts, hydrological processes and water engineering techniques have also been included to clarify the concepts and help forming clear mental image of the developments. While revising, the title of the report has been slightly changed from “Hydrology in Ancient India” to “Hydrologic Knowledge in Ancient India”. I compliment the authors of the first edition of the report for their vision and efforts. I thank Dr. Suhas Khobragade, Scientist-F; Dr. P. K. Singh, Scientist-D; Dr. A. K. Lohani, Scientist-G; Md. Furqan Ullah, ALIO; and Mrs. Charu Pandey, LIA for their sincere efforts to update the report. In this report, material from various sources has been compiled. The sources and their contributors are duly and thankfully acknowledged.

A softcopy of the report and more information about the institute is available at www.nihroorkee.gov.in.


(Sharad K Jain)
Director

Roorkee, Dec. 01, 2018

Preface to the First Edition

While making a reconnaissance of ancient Indian literature it was found that it contains a gold mine of knowledge in hydrology. This encouraged the Institute to attempt a thorough study of various available ancient literature to arrive at a document compiling the wealth of hydrological treasures hidden in Indian literature. The report attempts at compiling information on various component processes of hydrology and their interaction.

While carrying out the studies on hydrological information in ancient Indian literature, it was heartening and revealing to note that the hydrological concepts which are coming to be discovered & invented in last 3 centuries were known and well documented in ancient Indian literature even as early as 3000 B.C.

Like other sciences, the science of water also was well developed in ancient India. It is regrettable that at present sufficient attention and respect is not being paid to our ancient Indian sciences. This is because somehow, we have developed a notion that ancient Indian sciences have lost all their utility in the face of modern sciences, which have developed so much to their present position. But this concept of ours will prove false if one tries to realize the real merits of the ancient Indian sciences. It is expected that present report will be able to porove this thing in the area of hydrology.

The attempted study reveals that the field of hydrologic-cum-indological investigation remained totally unearthed and unexplored. This sort of report exploring the knowledge of hydrology as contained in the ancient Indian literature had become a crying need of the day, specially when hydrology has come to occupy its rightful place in India in the modern era. I am sure that if the ancient Indian hydrology is revived and brought to practical use it will prove of much benefit to the India in particular and to mankind as a whole.

This valuable document has been prepared by Shri T.M. Tripathi, Scientist 'B' and other scientists and staff of the Institute. A number of libraries of the country were consulted however special mention needs to be made of libraries of Gurukul Kangari University, Haridwar and Sampurnanand Sanskrit University, Varanasi.

Dated: Sept.7, 1990


(SATISH CHANDRA)
DIRECTOR

CONTENTS

Title	Page No.
Preface to the Second Edition	iii
Preface to the First Edition	v
List of Figures	ix
List of Tables	ix
List of Abbreviations	xi
Summary	xiii
Chapter 1: Introduction	01
Chapter 2: Hydrologic Cycle	13
Chapter 3: Cloud Formation, Precipitation, and its Measurement	25
Chapter 4: Interception, Infiltration and Evapotranspiration	53
Chapter 5: Geomorphology and Surface Water	63
Chapter 6: Ground Water	69
Chapter 7: Water Quality and Waste Water Management	79
Chapter 8: Water Resources Utilization, Conservation and Management	91
Chapter 9: Concluding Remarks	99
Bibliography	101
Glossary of Terms	107

LIST OF FIGURES

Fig. No.	Title	Page No.
1.1	The Great Bath of Mohenjo-Daro	05
1.2	Sophisticated Water Reservoir at Dholavira, evidence for hydraulic sewage systems in the ancient Indus Valley Civilization	06
2.1	Representation of the various processes of the hydrologic cycle	13
2.2	Schematic Representation of the Hydrological Cycle extracted from Kishkindha Kanda of Ramayana of Valmiki by Malik (2016)	22
2.3	Schematic comparisons between Modern Hydrological cycle and hydrological cycle concept in Valmiki Ramayana by Malik (2016)	22
3.1	The process of Cloud Formation	26
3.2	The Symon's raingauge (Modern raingauge)	49
6.1	Wells discovered at Lothal, 2600 BC	69
6.2:	Unconfined aquifer showing different zones	71
7.1	Drainage and sanitation systems of Mohenjo-Daro and Lothal cities of Indus valley civilization	89
8.1	Ahar Pyne system in Gaya, South Bihar	94
8.2	A view of Sudarsana lake Girnar, Junagadh, Gujarat	95

LIST OF TABLES

Table No.	Title	Page No.
1.1	Some selected shlokas (prayers) invoking water as God	07

LIST OF ABBREVIATIONS

(with approximate date of works)

A.V.	Atharva Veda (Latest Veda, Before 800 B.C.)
BP	Bhava Prakash (16 th Century A.D.)
Brahmand	Brahmanda Purana (3 rd – 4 th century A.D.)
Garuna	Garuna Purana (6 th Century B.C.-7 th Century A.D)
GB	Gopatha Brahmana (around 1000 B.C.)
Kurma	Kurma Purana (600 B.C. to 700 A.D.)
Linga	Linga Purana (600 B.C. to 700 A.D.)
M.B.	Mahabharata (400 B.C. to 400 A.D.)
Markandeya	Markandeya Purana (6 th Century B.C. to 4 th Century A.D.)
Matsya	Matsya Purana (6 th Century B.C. to 4 th Century A.D.)
Narada	Narada Purana (600 B.C. to 275 A.D.)
Padma	Padma Purana (600 B.C.-400 A.D.)
Rama.	Ramayana (800 B.C.-200 B.C.)
R.V.	Rig Veda (3000 B.C. or before)
S.V.	Sam Veda (3000 B.C.)
SB	Satpatha brahmana (2000 B.C.)
Skanda	Skanda Purana (7 th century A.D.)
Tai. Ara.	Taithiriya Aranyaka
T.S.	Taithiriya Samhita (later than Rig Veda, 1500 B.C.-800 B.C.)
Vais. Sutr.	Vaisesika Sutra (600 B.C.-700 B.C.)
Vayu	Vayu Purana (200 B.C.-400 A.D.)
Vishnu	Vishnu Purana (600 B.C.-275 A.D.)
Y.V.	Yajurveda (later than Rig Veda, 1500 B.C.-800 B.C.)

SUMMARY

Our existence is dependent on water in many ways. Infact, one could say that our whole civilization is built on the use of water. India is a country with more than five thousand years of civilization, with great contributions to the field of hydrology. Ancient Indian civilization, referred to as Indus Valley Civilization or Harappan Civilization was at its prime around 3300–1300 BC. It is now known that Harappan people had sophisticated systems of water supply and sewerage, including hydraulic structures such as dams, tanks, lined wells, water pipes and flush toilets. The cities of Harappa and Mohenjo-Daro developed the world's first urban sanitation system. Large scale agriculture was practiced and an extensive network of canals was used for the purpose of irrigation in Indus valley civilization. Sophisticated storage systems were developed including the reservoir built at Girnar in ca. 3000 BC.

The ancient Vedas, Puranas, Meghmala, Mayurchitraka, VrahtSamhita, literature of Buddhism and Jainism and various other works are enriched with plethora of knowledge about natural systems, including earth, atmosphere, hydrosphere, lithosphere and their interaction with the human beings. If one studies these ancient Sanskrit literature, (s)he observes that it contains valuable references to hydrology. It is observed that in ancient India, the information on various hydrological processes was very well known. Evaporation, condensation, cloud formation, precipitation and its forecasting were well understood in ancient India. Raingauges were developed and were widely used during the Mauryan period (4th cent. B.C.) to measure rainfall and its seasonal variation, based on the same principles as that of modern hydrology. While the western knowledge about the occurrence of ground water was based on wild theories, the Indians had well-developed concepts of ground water occurrence, distribution and utilization. Literature also reveals that hydrologic indicators were used to detect the presence of ground water. Well organized water pricing system was also in place during Mauryan era. Various references are available in Vedas alluding the importance of efficient water use so as to reduce the intensity of water scarcity and drought etc.

In the present report, an attempt has been made to compile knowledge and wisdom pertaining to hydrology in ancient Indian literature. At this juncture, it is high time that we recognize and appreciate our traditional wisdom and practices and blend them appropriately with our current systems of water management. Such overdue initiative will definitely create a synergy of the OLD and the NEW.

Chapter-1

INTRODUCTION

Science improves our knowledge of the nature and living beings. It helps the humans to investigate the several unknowns of the universe and generates solutions for practical problems. In fact, science has several functions, including the attempt to improve the quality of the human life. In ancient days, although science was unknown as such, yet man had realized the importance of water for survival, and therefore, the earliest civilizations were distinctly and predominantly hydraulic in character as they owed their origin to reliable sources of water to meet their various needs. Rivers played such a pivotal role in the life and living of those people that their civilizations came to be known as river valley civilizations. Prominent among these were the Nile valley civilization in Egypt, the Tigris valley civilizations in Mesopotamia, the Howang-Ho valley civilization in China and the Indus valley civilization in India. Most of these civilizations existed from 3500 to 300 BC and there are historical evidences to show that certain engineering measures were adopted by them to sustain as well as enhance benefits from rivers and also to protect against damages due to floods and droughts.

Humankind established permanent settlements about 10,000 years ago when people adopted an agrarian way of life. Due to settled and somewhat secured life, population began to expand faster than ever before. Settled agricultural life made it possible to construct villages, cities and eventually states, all of which were highly dependent on water (Vuorinen et al., 2007). This created a unique relationship between humans and water. Most of the ancient civilizations, i.e., Indus valley, Egyptian, Mesopotamian and Chinese were developed at places where water required for agricultural and human needs was readily available, i.e., close to springs, lakes, rivers and at low sea levels (Yannopoulos et al., 2015). Most ancient civilizations were highly developed and technologically equipped for societal sustainability as well as to enhance benefits from rivers and also to protect against damaging floods and other hydrological extremes. Water transport over long distances was based on gravity. Thus, long aqueduct systems (indeed, sometimes exceeding 100 km) were used to convey water over large distances, using gravity. Also, water cisterns for harvesting rainwater, canals and ground water wells were practiced since the Bronze Age (ca. 3200–1100 BC). However, fall of these civilizations and gradual decay of some of them were partly prompted by mankind's creeping inability to cope up with adverse and

damaging consequences of his interference with hydrology and hydraulics of the respective rivers in his attempts to derive benefits. Scarborough et al. (2003) and Ortloff et al. (2009) have reviewed how water management affected ancient social structures and organization through typical examples in the Eastern and Western hemispheres, covering the whole ancient world.

It is well known that in the realm of spiritual values, the Indian heritage has been great and sublime and perhaps unparalleled, as testified by some of the great personalities of the west who underwent the toil of learning Sanskrit and presenting the world with translation of the renowned texts of Vedas and Upanishads in English and German. Besides the spiritual growth, ancient India also exhibited the growth of science. The Indus Valley civilization, one of the earliest and most developed civilizations of that time, was the world's largest in extent and epitomises the level of development of science and societies in proto-historic Indian sub-continent. Ancient Indian literature, dating back from the age of the Vedas, further witnesses this development of sciences (including the water science). It is a good fortune that the ancient Indian Sanskrit works have been preserved and not lost through centuries of domination by alien races and alien cultures in India.

Science in Ancient India

Very few workers in the scientific world are aware of how much science, as understood and accepted by scientists, is contained in the ancient Sanskrit literature. It is a moot question whether the ancient sages had adopted the methods of modern science of laboriously collecting observational data and integrating them through appropriate concepts into useful and acceptable truths. Observation as a medium of realizing the underlying truths could not have been ignored.

Science is defined as ordered knowledge of natural phenomena and the rational study of the relations between the concepts in which these phenomena are expressed. It is in its widest sense, “a systematic method of describing and controlling the material world”. It can be seen, as it stands at any moment, as a logical and coherent account of that order which the scientists of the time find in nature. It progressively affects man’s life.

In India, at the beginning of the third/fourth millennium B.C., a highly developed civilization, popularly known as the Indus Valley civilization or Harappan Civilization (a Bronze Age civilization) grew in parts of Pakistan and northwest India, on the fertile plains of the Indus River. The Harappan civilization was mainly located in present-day Indian states of Gujarat, Haryana,

Punjab, Rajasthan, Uttar Pradesh, Jammu and Kashmir; and present-day Pakistan provinces of Sindh, Punjab, and Balochistan. It was located mainly in the region of the Indus and Ghaggar-Hakra Rivers. The major urban centres were at Harappa, Mohenjo-daro, Dholavira, Ganeriwala and Rakhigarhi.

The people of the Indus Civilization made great scientific advancements. They achieved great accuracy in measuring length, mass, and time. These people were among the first to develop a system of uniform weights and measures. Preparation of the Vedic calendar for various ceremonies and of rituals necessitated the study of heavenly bodies and of their movements. This led to the advancement of the astronomical Science (Prasad, 1980). The fact that sun light constitutes seven colour rays was known to Vedic Aryans, as evident from the following shloka of the Rig Veda (RV.II,12.12),

यःसप्तरश्मिर्वृषभस्तुविष्मानवासृजत्सर्वेसप्तसिन्धून् ।

योरोहिणमस्फुरद्वज्रबाहुर्घामारोहन्तं स जनासइन्द्रः । (RV.II,12.12)

Meaning: the sun containing seven colour rays is the cause of water flow in the rivers (because of rain). After rain, it again attracts water from earth and this cycle goes on.

Indian arithmetic is remarkable in that there is evidence to show that as early as third century B.C., a system of notation was evolved from which the scheme of numerals that is in vogue even today has been copied. The Aryabhatta (476–550 CE), a great mathematician and astronomer, studied the summation of arithmetic series and attempted to solve quadratic indeterminate equations. Brahmagupta, the great mathematician of 7th century, developed application of explicitly general algebraic methods to astronomical problems. The beginning of the medical sciences goes back to the age of the Vedas. The early beginnings of the art of healing and of the knowledge of healing herbs are found in the ‘Kausikasutra’ of the ‘Atharvaveda’. Susruta and Charaka were well known surgeons and physicians. During the Buddhist period, renowned scholar Jivaka was famous for his amazing medical and surgical cures. Medicine was also an important and compulsory subject in the ancient universities of Taksasila, Nalanda and Vikramasila. The medical work of Vagbhata of the seventh century contains the first mention of mercury (Prasad, 1980). The most remarkable feature of the Buddhist Philosophy of India is the formulation of the atomic theory by Kanada (600 B.C.) (Prakash, 1965). Biswas (1969) has rightly remarked that the growth of modern science in Europe would have been hardly possible

without the background of pioneering contributions from India, China and Arabian countries, well up to the 12th century A.D.

Domination of the foreign rulers for a long time did not help in bringing the scientific content of the Sanskrit and other literature to come to the fore. Even after independence, the situation did not improve for the obvious reason that there is no interaction between the modern scientists and the Sanskrit scholars. The scientist never bothered to know about the scientific content in the ancient Sanskrit literature while the Sanskrit scholars never cared to bring to focus the problems of scientific nature available in the Sanskrit works. They got entangled themselves in problems such as ‘Vyakarana’, Mimansa’ etc. Hence, even to date, the scientific contents of the ancient works have remained almost wholly unknown and unanalyzed.

Significance of Water in Indian Traditions

Since ancient times India is known as the land of culture and spiritualism. Water has always had a pervasive influence on the cultural and the religious life of Indian people. The Great Bath of Mohenjo-Daro is a great testimony to this fact (Fig. 1.1). The bath is considered by scholars as the "earliest public water tank of the ancient world". Although, the exact significance of the structure is unknown, most scholars agree that this tank was used for special religious functions.



Fig. 1.1: The Great Bath of Mohenjo-Daro (Source: Wikipedia)

Drier climates and water scarcity in India led to numerous innovations in water management. Since Indus valley civilization. Irrigation systems, different types of wells, water storage systems and low cost and sustainable water harvesting techniques were developed throughout the region. The reservoir built in 3000 BC at Girnar and the ancient step-wells in Western India are examples of some of the skills. Technologies based on water were also prevalent in ancient India. Reference to the manually operated cooling device “Variyantra” (revolving water spray for cooling the air) is given in the centuries old writing “Arthashastra” of Kautilya (400 BC). The “Arthashastra” and “Astadhyayi” of Panini (700 BC) give reference to rain gauges (Nair, 2004).



Fig. 1.2: Sophisticated Water Reservoir at Dholavira, evidence for hydraulic sewage systems in the ancient Indus Valley Civilization (Source: Wikipedia).

In the Vedic and other Indian traditions, all natural forces including planets and rivers are personified as gods and goddess and worshipped. Early Indian culture originated near river regions. As a matter of fact, the very name of the country is derived from the name of river Indus. The seven rivers namely Ganga, Yamuna, Saraswati, Narmada, Godavari, Krishna and Kaveri are considered important on cultural basis. For example, the Holy River Ganges is mythologically linked to Lord Shiva and is considered by the Hindus as the symbol for purification of the soul and rejuvenation of the mind. All over India people throng for a dip in the holy river to wash away their sins. Divine water is consumed in the temple after puja worship rituals; idols of worship are sprinkled with water (abhishekam); and a plantain leaf kept for a meal is cleaned with water and a prayer. Table 1.1 presents some of the important shlokas in the Sanskrit which are invoked while offering prayers to water as God.

Table 1.1: Some selected shlokas (prayers) invoking water as God

SHLOKA	MEANING
आपो हिष्ठा मयोभुवस्था न ऊर्जे दधातन । महे रणाथ चक्षसे ॥१॥	हे जल ! आपकी उपस्थिति से वायुमंडल बहुत तरोताज़ा है और हमें उत्साह और शक्ति प्रदान करता है। आपका शुद्ध सार हमें प्रसन्न करता है इसके लिए हम आपको आदर देते हैं । O Water, because of your presence, the atmosphere is so refreshing, and imparts us with vigour and strength. We revere you who gladdens us by your pure essence.
यो वः शिवतमो रसस्तस्य भाजयतेह नः । उशतीरिव मातरः ॥२॥	हे जल ! आप अपना यह शुभ सार कृपया हमारे साथ साझा करें जिसप्रकार एक मां की इच्छा होती है की वह अपने बच्चों को सर्वश्रेष्ठतम प्रदान करे । O Water, this auspicious sap of yours, please share with us, like a mother desiring (to share her best possession with her children).
तस्मा अरं गमाम वो यस्य क्षयाय जिन्वथ । आपो जनयथा च नः ॥३॥	हे जल ! जब आपका उत्साही सार किसी दुखी प्राणी को प्राप्त होता है तो वह उसे जीवंत कर देता है । हेजल ! इसलिएआपहमारेजीवनदाताहैं। O Water, when your invigorating essence goes to one affected by weakness, it enlivens him, O Water, you are the source of our lives.
शं नो देवीरभिष्टय आपो भवन्तु पीतये । शं योरभि स्रवन्तु नः ॥४॥	हे जल ! जब हम आपका सेवन करते हैं तो उसमें शुभ दिव्यता होने की कामना करते हैं । जो शुभकामनाएँ आपमें विद्यमान हैं , उसकाहमारे अंदर संचरण हो। O Water, may the auspicious divinity which is wished for, be present in you when we drink (water). May the auspiciousness which supports you, flow to us.
ईशाना वार्याणां क्षयन्तीश्वर्षणीनाम् । अपो याचामि भेषजम् ॥५॥	हे जल आपकी दिव्यता कृषि भूमियों में भी संचरित हो ! हे जल, मेरा आग्रह है कि आप फसलों का समुचित पोषण करें। O Water, may the divinity in Water dwell in the farm lands. O Water, I implore you to give nutrition (to the crops).

<p>अप्सु मे सोमो अब्रवीदन्तर्विश्वानि भेषजा । अग्निं च विश्वशंभुवम् ॥६॥</p>	<p>हे जल , सोमा ने मुझे बताया कि जल में दुनिया की सभी औषधीय जड़ी बूटीयाँ और अग्नि जो दुनिया को सुख समृद्धिप्रदान करती है भी मौजूद है।</p> <p>O Water, soma told me that in water is present all medicinal herbs of the world, and also agni (fire) who brings auspiciousness to the world.</p>
<p>आपः पृणीत भेषजं वरूथं तन्वेऽ मम । ज्योक्च सूर्यं दृशे ॥७॥</p>	<p>हे जल, आपमें औषधीय जड़ी बूटीयाँ प्रचुर मात्रा में समायी हुई हैं; कृपया मेरे शरीर की रक्षा करें, ताकि मैं सूर्य को लंबे समय तक देख सकूँ (अर्थात् मैं लंबे समय तक जीवित रह सकूँ)।</p> <p>O Water, you are abundantly filled with Medicinal Herbs; Please protect my body, so that I can see the sun for long (i.e. I live long).</p>
<p>इदमापः प्र वहत यत्किं च दुरितं मयि । यद्वाहमभिदुद्रोह यद्वा शेष उतानृतम् ॥८॥</p>	<p>हे जल, मुझमें जो भी दुष्ट प्रवृत्तियाँ हैं, कृपया उन्हें दूर करें और मेरे मस्तिष्क में विद्यमान समस्त विकारों को दूर करें और मेरे अंतर्मन में जो भी बुराईयाँ हैं उन्हें दूर करें।</p> <p>O water, please wash away whatever wicked tendencies are in me, and also wash away the treacheries burning me from within, and any falsehood present in my mind.</p>
<p>आपो अद्यान्वचारिषं रसेन समगस्महि । पयस्वानग्न आ गहि तं मा सं सृज वर्चसा ॥९॥</p>	<p>हे जल, आप जो उत्साही सार से भरे हुए हैं मैं आपकी शरण में आया हूँ । मैं आप में गहराई से सम्महित हूँ .अर्थात् स्नान कर. से घिरा हुआ है .अग्नि सिद्धांत. जो अग्नि. मुझमें चमक पैदा करे।</p> <p>O Water, today, to you who is pervaded by fine rasa (invigorating sap) I came, I deeply enter (i.e. bathe) in you who is pervaded by agni (fire principle); may that agni produce lustre in me.</p>

Hydrologic Knowledge in Ancient India

The historical development of hydro-science has been dealt by many writers (Baker and Horton, 1936; Chow, 1964; Biswas, 1970); but in all these works references to the contributions made in ancient India is conspicuously absent (Prasad, 1980). Chow (1964), for example, describing the history of hydrology, has referred to the works of Homer, Thales, Plato, Aristotle in Greece, Pliny in Rome and many Biblical scholars of that time but has not made any reference to any

Indian scholars and literature, and their great contributions. Most of these western scholars believed in the wild theories regarding origin of water. Thales, an Ionian philosopher, mathematician and astronomer for example, stated that the sea water driven into rocks by wind is the cause of ground water. Plato (427-347 B.C.), the great Athenian philosopher, stated that the water of seas, rivers, springs etc. come from a large underground reservoir and goes back to the same. Aristotle (384-322 B.C.) said that water of the springs etc. is derived from the underground water through system of underground openings. Famous Stoic philosopher Lucius Annacus Sencca (4 B.C.) declared that rainfall cannot be the source of springs and underground water, because it penetrates only a few feet into the earth (Prasad, 1980). Marcus Vitruvius who lived about the time of Christ conceived a theory saying that ground water is part of rainfall originated through infiltration. All these theories of the western scholars indicate a low level of development of hydrosience in the western world during ancient times. On the other hand, contemporary Indian scholars appear to have developed an advanced level of knowledge about the various aspects of water science, as reflected in the ancient Indian literature which contains very valuable and important scientific discourses on hydrology and their practical applications. There are adequate archaeological evidences to testify that the Harappans of the Indus Valley were well aware of the seasonal rainfall and flooding of the river Indus during the period between 2500 and 1700 B.C., which is corroborated by modern meteorological investigations (Srinivasan, 1975). The Vedic texts, which were composed probably between 1500 and 1200 BC (1700–1100 BC according to some scholars), contain valuable references to ‘hydrological cycle’. The important concepts of hydrology are scattered in the Vedas in various verses, in the form of hymns and prayers addressed to various deities. Likewise, other Sanskrit literature also contains valuable knowledge related to the science of hydrology.

The origin and evolution of agriculture and experience in irrigation on the territory of India or anywhere in the world are not separate processes, as evidenced from following hymns of the Yajur Veda:

कृषिश्चमे यज्ञेनकल्पंताम ।

वृष्टिश्चमे यज्ञेनकल्पंताम ॥ यजुर्वेद, 18–9 ॥

मारुतश्चमे यज्ञेनकल्पंताम ॥ यजुर्वेद, 18–17 ॥

These hymns illustrate the importance of Yajna’s (यज्ञ; Sacrifice) for rain, agriculture, and air or environment and their interrelationship.

That water is not lost in the various processes of the hydrological cycle namely evaporation, condensation, rainfall, streamflow etc., but gets converted from one form to other was known during Vedic and later times. Water uptake by plants, division of water into minute particles by sun rays and wind, different types of clouds, their heights, their rainfall capacities etc. along with the prediction of rainfall quantity in advance by means of observing the natural phenomena of previous years are also available in Puranas, Vrhata Samhita (550 A.D.), Meghamala (900 A.D.) and in other literature. The references to rain gauges are available in Arthashastra of Kautilya (400 B.C.), and Astadhyayi of Panini (700 B.C.). The quantity of rainfall in various parts of India was also predicated by Kautilya. Indians were acquainted with cyclonic, orographic effects on rainfall and radiation, and convectional heating of earth and evapotranspiration. Various other aspects such as infiltration, interception, stream flow and geomorphology, erosive action of rainfall, etc. were also known. In Ramayana (200 B.C.) the reference to artesian wells is available. Ground water development and water quality consideration were also getting sufficient attention in ancient India is evident from the Vrhata Samhita (550 A.D.).

References to water management and conservation, well organized water pricing system around 400 B.C., construction methods and materials of dam, tanks etc., bank protection, spillways etc. in the ancient Sanskrit literature reflect the high stage of development of water resources and hydrology in ancient India. Numerous references exist in Vedic literature, Arthashastra, Puranic sources, Vrhata Samhita, Mayuracitraka, Meghamala, Jain, Buddhist and other ancient Indian literature which illustrate the status of hydrology and water resources in ancient India. The various elements of hydrology and water resources as they are discussed in are inferred from the various ancient Indian literature and also discussed by some of the authors such as Tripathi (1969), Prasad (1980), Prasad (1987), and others have been reviewed, analyzed and presented in this volume.

The various aspects of knowledge hydrology and water resources in ancient India have been discussed and presented in this report under the following chapters:

1. Introduction
2. Hydrologic Cycle
3. Cloud Formation, Precipitation, and its Measurement
4. Interception, Infiltration and Evapotranspiration,
5. Geomorphology and Surface Water

- 6. Ground Water**
- 7. Water Quality and Waste Water Management**
- 8. Water Resources Utilization, Conservation and Management**
- 9. Concluding Remarks**

HYDROLOGIC CYCLE

Hydrologic Cycle is a fundamental and important concept in hydrosience. The cycle involves the total earth system comprising the atmosphere (the gaseous envelop), the hydrosphere (surface and subsurface water), lithosphere (soils and rocks), the biosphere (plants and animals), and the Oceans. Water passes through these five spheres of the earth system, in one or more of the three phases: solid (ice), liquid and vapour. Figure 2.1 represents the various processes of the hydrologic cycle.

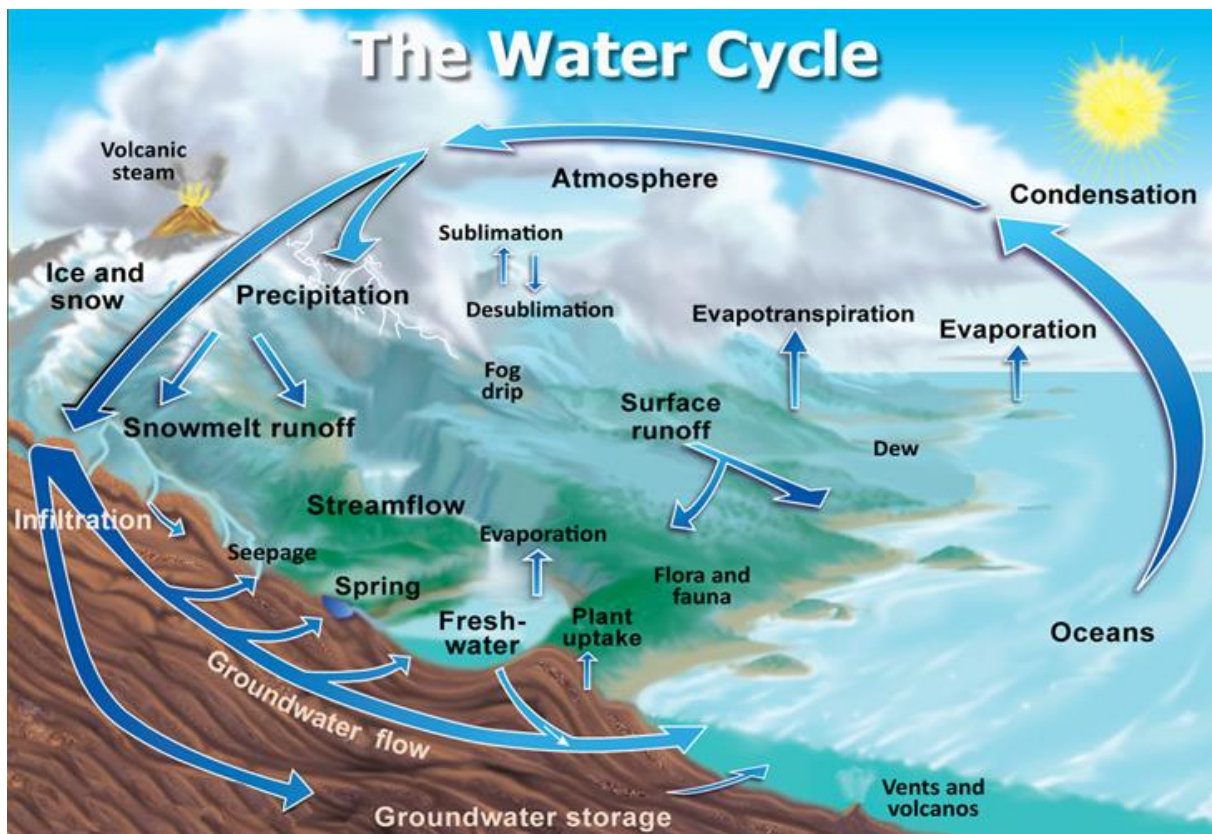


Figure 2.1: Representation of the various processes of the hydrologic cycle
(Source: John Evans and Howard Periman, USGS - <http://ga.water.usgs.gov/edu/watercycle.html>)

The Vedic texts which are more than 3000 years old contain valuable references to water and the ‘hydrologic cycle’. As mentioned earlier, the most important concepts, on which the modern science of Hydrology is founded, are mentioned in Rig Veda in various verses in the form of hymns and prayers addressed to various deities and divinities such as Indra (firmament), Agni (fire), Maruts (wind) and so on. For example, a verse from Rig Veda states like this:

आदह स्वाधामनु पुनर्गर्भत्वमेरिरे ।
दधानानामः यज्ञियम् ॥ R.V., I,6.4 ॥

It means that the water which gets divided in minute particles due to the heat of sun is carried by wind and after the conversion into cloud it rains again and again. Another verse of the Rig Veda (R.V, I,7.3) states that the God has created sun and placed it so, that the whole universe gets illuminated, likewise this is the rule of universe to extracts up water continuously and then convert it to cloud and ultimately discharge as rain.

इन्द्रो दीर्घाय चक्षस आ सूर्य रोहयादिदति ।
वि गोभिराद्रिमैरयत ॥ R.V. I,7.3 II

Following verses of Rig Veda explain the transfer of water from earth to the atmosphere by the wind (I, 19.7), breaking up of water into small particles and evaporation due to sun rays and subsequent rain (I, 23.17), the formation of cloud due to the water evaporated from the mother earth and its come back to its mother in the form of rain (I,32.9).

The verse I,32.10 of the Rig Veda says that the water is never stationery. It continuously gets evaporated and comes down, but due to smallness, we can't see the rising water particles.

य ईखड्यन्त पर्वमतान् तिरः समुद्रमर्णवम् ।
मरुद्भिरग्न आ गहि ॥R.V., I,19.7 II

अमूर्या उप सूर्ये याभिर्वा सूर्यः सह ।
ता नो हिन्वन्त्वध्वरम् ॥R.V., I,23.17 ॥

नीवातयां अभवद्वृत्रपुत्तेन्द्रो अस्या अव अधर्जभार ।
उत्तराः सूरधरः पुत्र आसीददनुः शये सहवत्सानधेनुः ॥ R.V., I,32.9 ॥

The following verses of the Rig Veda say that the rays of the Sun are the cause of rains and that the sun extracts water from all parts of the world and the start of creation is through fire only, which is continuously engaged in extraction and discharge of water.

अतिष्ठन्तीनाम विवेशनानां काष्ठानां मध्ये निहितं शरीरम् ।
वृत्रस्य निण्यं वि चरन्त्यापो दीर्घतम् आशयदिन्द्रशत्रुः ॥R.V., I,32.10 ॥

ऋतं देवाय कृष्वते सवित्र इन्द्रायाहिघे न रमन्त आपः ।

अहरह्यात्यक्तुरपां कियात्या प्रथमः सर्ग आसाम् ।।R.V., II,30.1 ।।

यो वृत्राय सिनमत्राभरिष्यत्प्र तं ज नित्री विदुष उवाब ।

पथो रदन्तीरनु जोषमस्मै दिवेदिवे धनुयो यन्त्यर्थम् ।।R.V., II,30.2 ।।

A verse of Rig Veda further states as follows:

या आपो दित्या उत वा स्त्रवन्त खनित्रिमा उत वा याः स्व्यंजाः ।

समुद्रार्या याः शुचवः पावकास्ता आपो देवीरिह मामवन्तु ।।R.V., VII,42.2 II

Meaning: The waters which are from heaven, of those which spring up by themselves, the bright pure waters that tend to the sea, may those divine waters protect me here. Like these verses, various other verses of the Rig Veda (RV. VIII,6.19, VIII,6.20; and VIII, 12.3) states the causation of water evaporation, formation of cloud, rain, flow of water and its storage in oceans etc.

The verse RV. X,27.33 of Rig Veda reads as follows:

देवानां माने प्रथमा अतिष्ठान्कृन्तत्रादेशामुपरा उदायन् ।

त्रयस्तपन्ति पृथिवीमनूषा द्वा बृबूकं वहतः पुरीषम ।।R.V., X,27.23 ।।

Meaning: At the start of creation, sun, etc. are created, rainfall is caused from sky and the vegetation is created by the combination of cloud, air and sun. The sun extracts water in the form of vapour & air, causes it to form cloud and rain.

Further elaboration of the knowledge about hydrologic cycle is found in the Sam Veda (VI-607).

A verse of Sam Veda reads as follows:

समन्या यन्त्युपयन्त्यन्याः समानमूर्व नघस्पृणान्ति ।

तम् शुचिं शुचयो दीदिवांसमपान्पातमुय यन्त्यायः ।।S.V. पूर्वाचिक VI, 607 ।।

Meaning: One type of water goes up and other type of water comes down, both of these may go to the atmosphere after treatment of sun's heat. From up they flow into rivers after rain and get stored there.

Similarly, the Yajur Veda explains the process of water movement from clouds to earth and its flow through channels and storage into oceans and further evaporation (Y.V., X-19).

प्र पर्वतस्य वृषभस्य पृष्णन्नावश्चरान्ति स्वसिचज्ञयानाः ।
ता आववृत्रन्नधरा गुदक्ता अहिं बुहन्यमनु रीयमाणाः
विष्णोर्विक्रमणमसि विष्णोर्विक्रान्तमसि विष्णोः क्रान्तमसि ॥Y.V., X-19 ॥

In the Rig Veda, Sam Veda and Yajur Veda the concept of infiltration, water movement, storage and evaporation as the part of hydrologic cycle are revealed clearly. During the time of Atharva Veda the concept of water evaporation, condensation, rainfall, river flow and storage and again repetition of cycle was explained as in the earlier Vedas. According to the Atharva Veda, the sun rays are the main cause of rain and evaporation, as mentioned below:

अमूर्या उप सूर्ये याभिर्ग सूर्यः सह ।
ता नो हिन्वन्त्वध्वरम् ॥ A.V., I,5.2 ॥

The verse I, 32.4 of the Atharva Veda states that the entry of rainwater into earth and its continuous movement in the cycle from earth to atmosphere is by sun rays. The Verse reads as below:

विश्वमन्यामभीवार तदन्यस्यामधि श्रितम् ।
दिवे च विश्ववेदसे पृथिव्यै चाकरं नमः ॥A.V.,I,32.4 ॥

Another Verse of the Atharva Veda (V,24.5) says that the water from earth goes to the atmosphere due to oxygen and then it comes down (rains) due to carbon dioxide.

मित्रावरुणौ वृष्ट्याधिपती तौ माक्ताम् ।
अस्मन् ब्रह्मण्यसिमन् कर्मण्यस्यां पुरोधायामस्यां प्रतिष्ठायामस्यां
चित्यामस्यामाकूत्यामस्यामाशिष्यस्यां देवहूत्यां स्वाहा ॥A.V., V,24.5 ॥

The hydrologic cycle reaches into the atmosphere and traverses, imparts, the domain of hydrometeorology. It may be seen in the Varahamihira's Vrhat Samhita (550 A.D.) in which three chapters are devoted to hydrometeorology comprising pregnancy of clouds (Chapter 21), pregnancy of air (Chapter 22), and quantity of rainfall (Chapter 23). Shlokas 1 and 2 of Dakargalam (Chapter 54 of Vrhat Samhita) which states the importance of science of ground water exploration, helps man to ascertain the existence of water are as follows:

धर्म्यं यशस्यं च वदाभवतोहं दकार्गलं येन जलोपलब्धिः ।
पुंसां यथाग्देषु शिरास्तथैव क्षितावपि प्रोन्नतनिनसंस्था
एकेन वर्णेन रसेन चाम्भश्च्युतं नभस्तो वसुधाविशेषांतु ।
नाना रसत्वं बहुवर्णतां च गतं परीक्ष्यं क्षितितुल्यमेव ॥ Vr.S., 54.1-2 ॥

The water veins beneath the earth are like vein's in the human body, some higher and some lower. The water falling from sky assumes various colours and tastes from differences in the nature of the earth. These shlokas imply that the infiltration of rainwater through the veins into earth surface is the source of ground water. The epic Mahabharata (XII, 183.15.16) explains that the water ascends to sky with the help of अग्नि (fire) and air and then its humidity get condensed and causes subsequent rainfall.

अग्निः पवनसंयुक्तः खं समाक्षिषते जलम् ।
सोग्निमारुतसंयोगाद् घनत्वमुपपद्यते । MB,XII,183.15 ॥
तस्याकाशे निपतितः स्नेहस्तष्ठति यो परः ।
स संघातत्वमापन्नो भूमित्वमनुगच्छति ॥ MB,XII,183.16 ॥

The verses 184.15-17 of the Mahabharata state that the plants drink water through their roots. The mechanism of water uptake by plants is explained by the example of water rise through a pipe. It is said that the water uptake process is facilitated by the conjunction of air.

पादैः सलिलपानाच्च व्याधीनां चापि दर्शनात् ।
व्याधिप्रतिक्रियत्वाच्च विद्यते रसनं द्रुमे ॥ MB,XII,184.15 ॥
वक्त्रेणोत्पलवालेन यथोर्ध्वं जलमाददेत् ।
तथा पवनसंयुक्तः पादैः पिबति पादपः ॥ MB,XII,184.16 ॥

In verse XII,362.4 and B of the Mahabharata, it is explained that the air and the sun rays get dispersed and fall on whole universe together. The Verse further says that the sun rains in rainy season (four months) and in next eight months the same water is again extracted by the sun rays. Thus, it explains two faces of hydrological cycle clearly viz.

यतो वायुर्विनिः सृत्य सूर्यरश्म्याश्रितो महान् ॥ M.B.XII,362.4 ॥

योष्टमासांस्तु शुविना किरणेनोक्षित पयः ।

प्रत्यादत्ते पुनः काले मिश्रचर्यमतः परम् ॥ M.B.,XII,362.B ॥

Like Vedas and Epics, in Puranas (which are dated between 6th century B.C. to 7th century A.D.) we get various references which show the development of knowledge of hydroscience during their periods. Matsya Purana (Vo. I, Chapter 54) reveals that the air saturated with moisture is the cause of creation (earth) viz.

वाय्वाधारा वहन्ते वै सामृताः कल्पसाधकाः ॥ Matsya I,54.15 ॥

In verses I,54.29-34 of the Matsya Purana and 51.23-24-25-26 of the Vayu Purana, we come across the knowledge of evaporation. According to these verses, burning of water and its conversion to smoke is caused by sun rays which ascend to the atmosphere with the help of air, which again rains in next 6 months for the goodness of the living beings. The various verses are given below:

ध्रुवेणाधिष्टताश्चापः सूर्यो वै गृह्य तिष्ठति

सर्वभूतशरीरेषु त्वापो ह्यानुश्चताश्चियाः ॥ Matsya I,54.29 ॥

दह्यमानेषु तेष्वेह जग्दमस्थावरेषु च ।

धूमभूतास्तु ता ह्यापो निष्क्रामन्तीह सर्वशः ॥ Matsya I,54.30 ॥

तेन चास्त्राणि जायन्ते स्थानमभ्रमयं स्मृतम् ।

तेजोभिः सर्वलोकेकेभ्य आदत्ते रश्मभिर्जलम् ॥ I,54.31 ॥

समुद्राद्वायुसंयोगात् वहन्त्यापो गभस्तयः ।

ततस्त्वृतुवशात्कालेपरिवर्तन् दिवाकरः ॥ I,54.32 ॥

नियच्छत्यापो मेघेभयः शुक्लाः शुक्लैस्तुरश्मभिः ।
अभ्रस्थाः प्रपतन्त्यापोवायुनासमुदीरिताः ॥ I,54.33 ॥

ततो वर्षति षण्मासान् सर्वभूतविवृद्धये ।
वायुभिस्तनितंचैव विधुतस्त्वग्निजाः स्मृताः ॥ Matsya I,54.34 ॥

In Linga Purana a full-fledged chapter (I,36) has been devoted to the science of hydrology. It explains evaporation, condensation and rainfall with suitable examples very scientifically and says that the water can't be destroyed, only its state is changed.

दन्दह्यमानेषु चराचरेषु गोधूमभूतास्त्वभ निष्क्रमन्ति ।
या या ऊर्ध्वं मारुतेनेरिता वे तास्तास्त्वभांयग्निनावायु च ॥ Linga I,36.38 ॥

अतो धूमाग्निवातानां संयोगस्त्वमुच्यते ।
वारीणि वर्षतीत्यभ्रमभ्रस्येशः सहस्रद्रुक् ॥ Linga I,36.39 ॥

Meaning: After getting by sun, the water contained in most of the materials on earth gets converted to smoke (vapour) and ascends to sky with the air and subsequently gets converted to cloud. Thus, the combination of smoke, fire and air is the cause of cloud formation. These clouds cause rainfall under the guidance of lord Indra, having thousand eyes.

Similarly verses I,36.66-67 of the Linga Purana say that the water is never destroyed or lost, but only converted from one form to other i.e. water to vapour by sun heat, then cloud and subsequent rainfall and loss of rainfall by wind etc. viz.

अस्यैवेह प्रसादात्तु वृष्टर्नाताभवदिदवजाः ।
सहस्र गुणमुत्स्रष्टूं मादत्ते किरणैर्जलम् ॥ Linga I,36.66 ॥

जलस्य नाशो वृद्धिर्वा नातत्येवास्य विचारतः ।
ध्रुवेणाश्रिष्टतो वायुवृष्टिः संहरते पुनः ॥ Linga I,36.67 ॥

Thus, it is evident that the Linga Purana contains clear concept of rainfall, evaporation, condensation, cloud formation etc., along with the knowledge that water cannot be created or

destroyed. Chapter 41, Vol. I of the Linga Purana furnishes some more knowledge about the change in the facets of hydrological cycle with months of the year. viz.

वसन्ते चैव ग्रीष्मे च शतैः स तपते त्रिभिः ।
वर्षास्वथो शरदि च चतुर्भिस्स्यं प्रवर्षति ॥ Linga I,41.30 ॥

चैत्रे मासि भवेदंशुर्धाता वैशाखतापन ।
जेष्ठे मासि भवेदिन्द्र आषाढे वार्यमा रविः ॥ Ling I,41.33 ॥

Likewise Vayu Purana also contains valuable references to hydrologic cycle. Vayu Purana (51.14-15-16) state like this:

आदित्यपीतं सूर्याग्नेः सोमं संक्रमते जलम् ।
नाडीभिर्वायुयुक्ताभिलोकाधानं प्रवर्तते ॥ Vayu,51.14 ॥

यत्सोमात्स्त्रवते सूर्यं तदभ्रेष्वतिष्ठते ।
मेघा वायुनिघातेन विसृजन्त जलं भुवि ॥ Vayu 51.15 ॥

एवमुत्क्षिप्यते चैव पतते च पुनर्जलम् ।
न नाशमु उदकस्यास्ति तदेव परिवर्तते ॥ Vayu 51.16 ॥

Meaning: The water evaporated by sun ascends to atmosphere through the capillary of air, and there gets cooled and condensed. After formation of clouds, it rains by the force of air. Thus, water is not lost in all these processes but gets converted from one form to other continuously.

Brahmanda Purana (II, Chapt. 9) also gives some information on the hydrologic cycle. It says that seven colour rays of the sun extracts water from all sources, by heating them (II,9.138-139). Thereafter, the clouds of different shapes and colours are formed. Then they rain with high intensity and great noise. (II,9.167-168). In this way, the fire of the sun is controlled. The very object of the chapter is the concept of the hydrologic cycle explaining different parts one by one.

नावृष्ट्या परिविश्येत वारिणा दीप्यते रविः ।
तस्मादयः पिबन्धो वै दीप्यते रविरंबरे ॥ II,9.138 ॥

तस्य ते रश्मयः सप्त पिबन्त्यंभो महार्णवात् ।

तेनाहारेण संदीप्ताःसूर्याः सप्त भवन्त्युत ॥ Brahmanda II,9.1391 ॥

सप्तधा संवृतात्मानस्तमाग्निं शमयंत्युत ।

ततस्ते जलदा वर्ष मुचंति च महौघवत् ॥ II,9.167 ॥

सुघोरमशिवं सर्व नाशयंति च पावकम् ।

प्रवृष्टश्च तथात्यर्थं वारिणापूर्यते जगत् ॥ Brahmanda II,9.168 ॥

The treasure of knowledge about hydrology and hydrologic cycle available in various ancient Indian literature has still not been explored fully. As observed by V. T. Chow (1974) in the Symposium organized by UNESCO in Paris in August, 1974 “*the history of hydrology in Asia is fragmentary at best and much insight could be obtained by further study*”. Although the efforts are on, they are not numerous. In a recent study, Malik (2016) has made efforts to extract and analyze the concept of hydrological cycle as understood from the Ramayana Epic, focusing on the conceptual aspects of hydrological cycle interpreted from the 28th sarga of 4th Kanda of Kishkindha Kanda of Ramayana by the great poet Valmiki. The Schematic representation of hydrological cycle extracted from Kishkindha Kanda of Ramayana of Valmiki by Malik (2016) is shown in Figure 2.2.

Malik (2016) has also compared the modern concept of the hydrologic cycle with the concept present during the Ramayana of Valmiki. The comparison is shown in Figure 2.3. From the comparative analysis of the two concepts, he observes that “in the modern concept sun throughout the year evaporates the oceanic water or water from others water bodies coupled with transpiration. But in the epic, there is no signature of transpiration. Also, contrasting difference occurs for run-off where present concept considering run-off, infiltration and sub-surface flow. In the epic concept of infiltration and sub-surface flow are found to be lacking”. However, if we ignore these limitations, the concept of Ramayana is outstanding and very close to the modern concept.

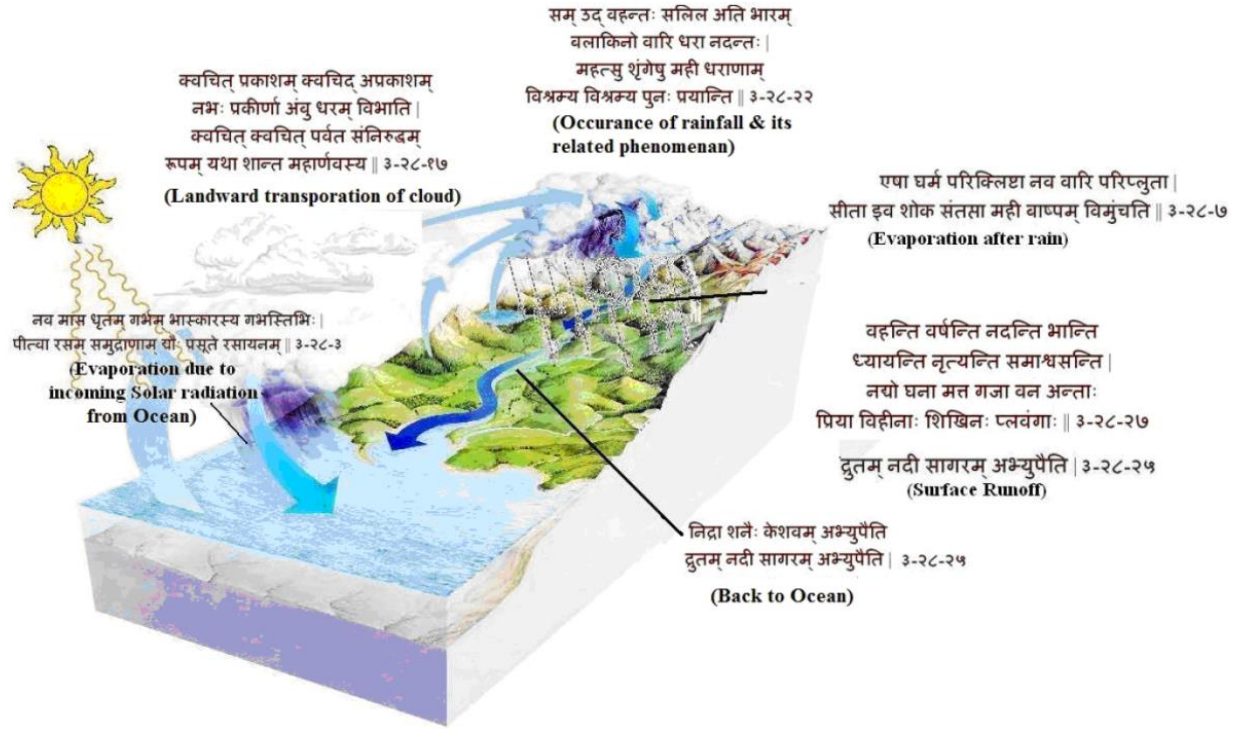


Figure 2.2: Schematic Representation of the Hydrological Cycle extracted from Kishkindha Kanda of Ramayana of Valmiki by Malik (2016)

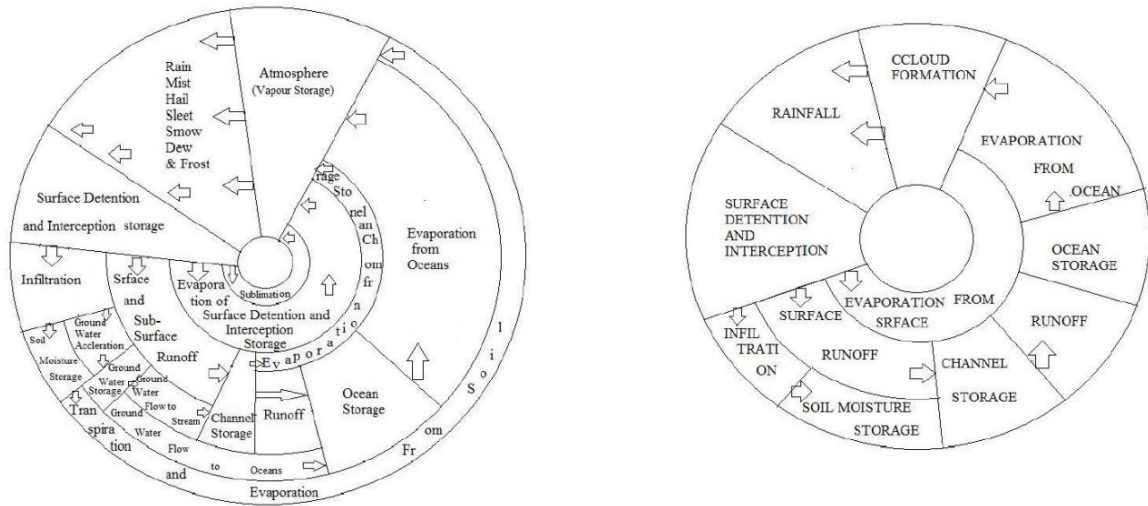


Figure 2.3: Schematic comparisons between Modern Hydrological cycle and hydrological cycle concept in Valmiki Ramayana by Malik (2016)

Epilogue

This chapter brings out that the knowledge of water science during the Vedic age and afterwards in the age of Epics and Puranas was highly advanced, although the people of those times were solely dependent upon their experience of nature, without sophisticated instruments of modern times. In the Vedic age, Indians had developed the concept that water gets divided into minute particles due to the effect of sun rays and wind, which ascends to the atmosphere by the capillary of air. It gets condensed there and subsequently falls as rainfall. Month-wise change in the facets of the hydrological cycle was also known. Water uptake by plants which gets facilitated by the conjunction of air along with the knowledge of infiltration is revealed in the ancient literature. From all above discourses, we can conclude that well developed concepts of the hydrological cycle were known to the ancient Indians in those ancient times while the contemporary world was relying on the wild theories of origin and distribution of water. Thus, the ancient Indian knowledge of water science can be regarded as the great achievement of that time.

CLOUD FORMATION, PRECIPITATION AND ITS MEASUREMENT

Precipitation is one of the three main processes (evaporation, condensation, and precipitation) that constitute the hydrologic cycle, the continual exchange of water between the atmosphere and Earth's surface. This chapter discusses various processes such as cloud formation, interaction between Sun and ocean and earth surface, condensation and precipitation, as described in the ancient Indian literature. The chapter also sheds lights on the techniques used for precipitation measurement in ancient India.

Seasons and Clod Formation

The Rig Vedic Aryans had keenly and carefully demarcated the variation in seasons and divided the whole year into six such divisions as the verse indicates:

उतो स मह्यमिन्दुभिः षड्युक्तो अनुसेषिधत् ।
गोभिर्यवं न चर्कृषत् ॥ R.V., I,23.15 ॥

The Sun was clearly known to the Rig Vedic Aryans as determinant of seasons and the seasons were formed for the benefit of the earthly creatures.

त्रीणि जाना परि भूषन्त्यस्य समुद्र एकं दित्येकमप्सु ।
पूर्वामनु प्र दिशं पार्थिवानामृतूत्प्राशासद्वि दधावनुष्टु ॥ R.V., I,95.3 ॥

Figure 3.1 shows the general cloud formation and associated processes, as understood in modern times. The knowledge about cloud formation is also present in the Rig Veda.

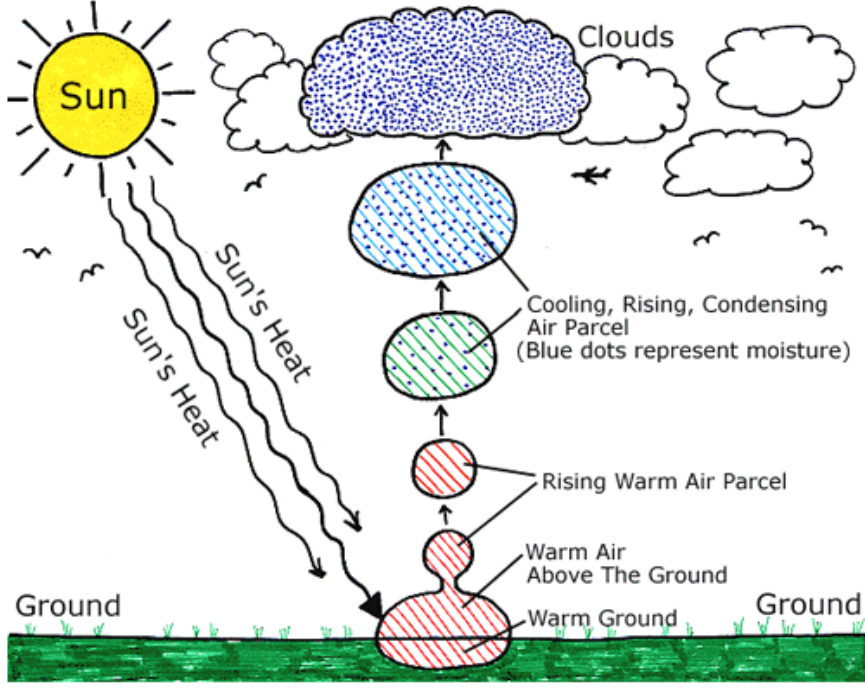


Figure 3.1: The process of Cloud Formation
(Source: <https://climate.ncsu.edu/edu/CloudFormation>)

Radiation, convection currents and rainfall as their effect, are described in the Rig Veda (I,164.47, VII, 70.2 and I,161. 11-12) through following verses.

उद्वत्स्वस्मा अकृणोतना तृणं निवत्स्वपः स्वपस्यया नरः ।

अगोस्यस्य यदसस्तना गृहे तद्घोदमृभवो नानु गच्छथ ॥ R.V., I,161.11 ॥

संमील्यं यद्भुवना प्सर्पत क्व स्वत्तात्या पितरा व आसतुः ।

अशपत यः करस्नं व आददे यः प्राबवीत्प्रो तस्मा अबवीतन ॥ R.V., I, 161.12 ॥

कृष्णं नियांन हरयः सुपर्णा अपो वसाना दिवमुत्पतन्ति ।

त आववृत्रन्त्सदनादृतस्यादिद्धृतेन पृथिवी व्युघते ॥ R.V., I, 164.47 ॥

These above verses of the Rig Veda also state that the rays of the Sun are the cause of the rains, and that the clouds are constituted of various elements. Some verses of Rig Veda (I,27.6; I,32.8; I,32.14; I,37.11; II, 24.4; V,55.3) describe the formation of cloud by evaporation of water by Sun and wind and then rainfall, and there is no other cause of rainfall other than Sun.

विभक्तासि चित्रभानो सिन्धोरूर्मा अपाक आ ।

सधो दाशुषे क्षरसि ॥ R.V., I, 27.6 ॥

नदं न भिन्ममुया शयानं मनो रुहाणा अतिं यन्त्यापः ।

यश्चिद्वत्रो महिना प्यतिष्ठत्तासामहिः पत्सुतः शीर्बभूव ॥ R.V., I,32.8 ॥

The above verses explain that all that water goes to the sky with wind by the heat of Sun rays and gets converted to clouds and then again after the penetration by Sun rays, it rains and gets stored in rivers, ponds, ocean etc. The clouds are said to be leaders for replenishment of water. The verse V 55.3 of the Rig Veda explains the simultaneous formation of mighty clouds which are co-dispensers of moisture.

साकं जाताः सुभवः साकमुक्षिताः श्रिये चिदा प्रतरं बावृधुर्नरः

विरोकिणः सूर्यस्येव रश्मयः शुभं यातामनु रथा अवृत्सत ॥ R.V., V,55.3 ॥

During Rig Vedic times the seasonal variation of rainfall was known, which is depicted through following verses (RV.VI,20.2 and VI,30.3) saying that the Sun extracts water from Earth during eight months and then this water rains during rainy season of four months.

दिवो न तुभयमविन्द्र सत्रासुर्यं देवेभिर्धायि विश्वम् ।

अहिं यत्तृत्रमयो वव्रिवांसं हन्तृजीषिन्विष्णुना सचानः ॥ R.V., VI,20.2 ॥

Verse I, 79.2 of the Rig Veda states that the Sun rays strike against moving clouds. Thus, the black shedders of rain roar. After this, the shower comes with delightful flashes of lighting. The rains then descend, and finally the clouds thunder.

अ ते सुपर्णा अभिनन्तं एवैः कृष्णो नोनाव वृषभो यदीदम् ।

शिवाभिर्न स्मयमानाभिरागात्पतन्ति मिहः स्तवयन्त्यभ्रा ॥ R.V., I,79.2 ॥

Following two verses (V.54.2 and V55.5) of the Rig Veda explain the cloud-bearing winds as the cause of rainfall, viz.

प्र वो मरुतस्तविषा उदन्यवो वयोवृधो अश्वयुजः परिज्रयः ।

सं विधुता दधति वाशाति त्रितः स्वरन्त्यापोऽवना परिज्रयः ॥ R.V., V,54.2 ॥

Meaning: “O cloud-bearing winds, your troops are rich in water, they are strengtheners of life, and are your strong bonds, they shed water and augment food, and are harnessed with steeds

(waves) that wander far and spread every-where. Combined with lighting, the triple-group (of wind, cloud and lightning) roars aloud, and the circumambient waters fall upon the earth”.

उदीरयथा मरुतः समुद्रतो यूयं वृष्टिं वर्षयथा पुरीषिणः ।

न वो दस्त्रा उप दस्यन्ति धनेवः शुभं यातामनु रथा अवृत्सत ॥ R.V. V,55.5 ॥

This verse explains that the cloud-bearing winds uplift water from ocean and charged with water shower down the rain. Similarly, instrumentality of winds in the causation of rainfall can be easily read in verses I,19.3-4; I, 165.1, and their relationship with clouds in I, 19.8 of the Rig Veda, as follows:

ये महो रजसो विदुर्विश्वे देवासो अद्रुहः । मरुद्भिरग्न आ गहि ॥

या उग्रा अर्कमानृचुरनाधृष्टास ओजसा भरुद्भिरग्न आ गहि ॥ RV.I,19.3-4 ॥

अ ते तन्वन्त रश्मिभिस्तिरः समुद्रमोजसा ।

मरुद्भिरग्न आ गहि ॥ RV.I,19.8 ॥

Both of the above verses reveal the cause of rain, who commands the rain to come down and execution of eternal laws.

The following hymn (I,38.7) of the Rig Veda reveals how the moisture laden winds bring some scanty rainfall in desert region also.

सत्यं त्वेषा अमवन्तो धन्वज्विदा रुद्रियासः ।

मिहं कृण्वन्त्यवाताम् ॥ R.V.I,38.7 ॥

From verse V,53.6-7 of the Rig Veda, we also come across the knowledge of Rig Vedic Aryans about the positive effect of yajna's (यज्ञ), forests and large reservoirs, causing rainfall.

आ यं नरः सुदानवो ददाशुर्षे दिवः कोशमचुच्यवुः ।

वि पर्जन्यं सृजन्ति रोदसी अनु धन्वना यन्ति वृष्टयः ॥

तत्तृदानाः सिन्धवः क्षोदसा रजः प्र सस्त्रुर्धेनवो यथा ।

स्यन्ना अश्वा इवाध्वनो विमोचने वि यद्वर्तन्त एन्यः ॥ R.V.V.,53.6-7 ॥

The following hymn from the Rig Veda (V, 53.17) indicates that there are sixty-three types of winds. However, their climatological and meteorological implications are still unraveled and they are mostly treated as merely mythologies.

सप्त मे सप्त शाकिन एकमेका शता दुदः ।

यमुनायमधि श्रुतमुद्राधो गत्यं मृजे नि राधो अश्वयं मृजे ॥ R.V.V,53.17 ॥

No clear cut mention of the monsoon is to be found in Rig Veda but the Marut hymns give satisfactory descriptions. Monsoon is, however, clearly referred to in the later period in the Yajurveda Samhita as सलिलवात (Taithriya IV.4.12.3).

वर्च इदं क्षत्र सलिलवातमुग्रम् ॥

धर्त्री दिशां क्षत्रमिदं दाधारोपस्थाशानां मित्रवदस्त्वोजः ॥ T.S,4.4.12.3 ॥

However, a better reference to rain bearing winds is provided in the Rig Veda (R.V. X. 137.2 and I,19.7).

द्वाविमौ वातौ वात आ सिन्धोरा परावतः ।

दक्षं ते अन्य आ वातु परान्यो वातु यद्रपः ॥ R.V.X,137.2 ॥

In versa, VIII,7.4 of the Rig Veda, the word मिहं is explained to mean mist, with which one cannot differ easily, if the content is taken into account, though at other places मिहं signifies rainfall.

वपन्त मरुतो मिहं प्र वेपयन्ति पर्वतान् । यद्यामं यन्त वायुभिः ॥ R.V.VIII,7.4 ॥

The importance of yajna to purify environment and causation of rainfall has also been described in the Rig Veda (RV.X,98.4; x,98.6/12; x.98.7 and x,98.11) as below:

आ नो द्राप्सा मधुमन्तो विशान्त्विन्द्र देह्याधिरथं सहस्त्रम् ।

निषीद होत्रमृतुथा यजस्व देवान्दे वाये हविषा सप्य ॥ R.V.X.98.4 ॥

अस्मिन्त्समुद्रे अध्युत्तरस्मन्पो देवोभिर्निवृता अतिष्ठन् ।

ता अद्रवन्नाष्टिणेन सृष्टा देवापिना प्रेषिता मृक्षिणीषु ॥ R.V.X.98.6/12 ॥

These hymns clearly describe that the water collected by Sun rays kept in kept in the sky safely, and to create rain, one should take help of knowledgeable priests, who will do appropriate yajna

(sacrifice) for rain. This implies that the precipitation is the result of weather and cloud formation. The three other Vedas, namely Sama, Yajur and Atharva Veda furnish some additional information on climatology and meteorology which we do not come across in the Rig Veda. Since these three Vedas chronologically belong to a later period, it can be easily seen that during the later Vedic period the water science further progressed to a considerable extent.

That the rain is a phenomena of ocean, wind and moisture, is proved to be clearly known by later Vedic times. Verse from the Taithriya says “from the Ocean, O Maruts ye make (the rain) to fall, O Ye that are rich in moisture (TS.II,4.8.2)”.

वृष्टयः उदीरयथा मरुतः समुद्रतो दूयं वृष्टिं वर्षयधा पुरीषिणः ।
सृजा वृष्टिं दिव अद्रिभः समुद्रं पृण ॥ TS.II,4.8.2 ॥

In Taithriya, it is also very clearly mentioned that the air circulation plays a definite role in the causation of rainfall. It is stated thus: “Verily becoming of like hue he (wind) causes Parjanya to rain (TS, II 4.9.I).

मारुतनसि मरुतामोज इति कृष्णं वासः कृष्णतूषं परि धत्त् एतद्वै
वृष्टये रुषं सरुप एव भूत्वा पर्जन्यं वर्षयति रमयत मरुतः श्येनमायिनमिति पश्चाद्वातं
प्रति मीवति पुरोवातमेव जनयति वर्षस्यावरुद्धयै वातमामानि जुहोति वायुर्वे वृष्टया ईशे
वायुमेव स्वेन भागधेयेनोप धावति स एवास्मै पर्जन्यं वर्षयस्य ष्टौ ॥ TS.II,4.9.1 ॥

West wind and the rain bearing monsoon or east wind are spoken of in above lines – “Stay O Maruts, the speeding falcon (with these words), he pushes back the west wind: verily he produces the east wind, to win the rains. He makes offering to the names of the wind, the winds rules the rain (TS.II,4.9.1).

During the Rig Vedic time, probably it was also known to the Aryans that plants (or forests) had some influence on the causation of rainfall.

सौभययैवाहत्या दिवो वृष्टमव रुन्धे मघुषा सं यौत्यपां वा एष ओषधीनां रसो
यन्मध्वभदय एवौषधीभयो वर्षत्यथो अद्भय एवौषधीभयो वृष्टिं नि नयति ॥ TS.II,4.9.3 ॥

Like RigVeda, the Yajur Veda also tells about the influence of yajna (sacrifice) in purifying air, water and environment as a whole, which helps in causation of rainfall. Hymn I,12 of the Yajur Veda reads as follows:

पावत्रे स्थो वैष्णव्यौ सवितुर्वः प्रसव उत्पुनाभयाच्छिदेण पवित्रेण सूर्यस्थ रश्मिभिः ।
देवीरापो अग्रेगुवो अग्रेपवो ग्र इममघ यज्ञ नयताग्रे यज्ञपतिं सुधातु यज्ञपतिं देवयुवम् ॥ YV.I,12 ॥

This mantra (hymn) states that the substances like water, air etc. get polluted and if they will be broken into minute articles by fire (with the help of yajna) they will get purified and pure rainfall will occur. The hymn VI.10 of the Yajur Veda states that the materials used in yajna get divided into minute atomic forms due to attraction of Sun and ascend to sky. This causes plenty of rain fall. Likewise hymns VI – 16 and XIII – 12 of the Yajur Veda also reveal the same fact as:

अपां पेरुरस्यापो देवीः स्वदन्तु सवात्तं चित्सद्देवहविः ।
सं ते प्राणो वातेन गच्छर्तो समङ्गानि यजत्रैः सं यज्ञपतिराशिषा ॥ YV.VI,10 ॥

In the Vedas at several places, the mist has been given the appellation of नीहार (Vajasaneyi Samhita 17.31) as:

न तं विदाथ य इमा जजानान्यघुष्माकमन्तरं बभूव ।
नीहारेण प्रावृता जल्पा चासृन्तु उक्थशासश्चरन्ति ॥ VS.XVII,31 ॥

The Yajur Veda knew about the immense concentration of mist or fog on water bodies and oceans “thou are ocean full of mist”. It was also known that pure waters purify all things through rain “May waters, like mother purify our bodies (YV.IV.2-3).

आपो अस्मान्मातरः शुध्रयन्तु घृतेन घृतप्यः पुनन्तु ।
विश्व हि रिप्रं प्रवहन्त देवीः ।
उदिदाभयः शुचिरा पूत एमिदीक्षातपसोस्तनूरसि
तां त्वा शिवा शग्मा परि दधे भद्रं वर्ण पुष्यन् ॥ YV.IV.2 ॥

The Sun was known to be the disperser of clouds and cause of rain “O Sun, thou bring rain on different parts of the earth”

महीनां प्योसि वचोदा असि वर्चो मे देहि ।

वृत्रस्यासि कनीनकरचक्षुर्दा असि चक्षुर्मे देहि ॥ YV.IV,3 ॥

The Sam Veda gives more emphasis on wooing Rain God. It clearly says that the eternal power of Sun penetrates the clouds and thus causes rain (SV. Previous II. 179). It also reveals that the Sun pours rain water on moving earth with the help of wind (SV. Previous II. 148) as;

यदिन्द्रो अनयाद्रितो महीरयो वृषन्तपः ॥

तत्र पूषा भुवत्सचा ॥ SV.Previous II.179 ॥

इन्द्रो दधीचो अस्थभिर्वृत्राण्यप्रतिष्कृतः ।

जधान नवतीर्नव ॥ SV. Previous II. 148 ॥

The other verses of Sam Veda (V.562; final V.906; and final X.1317) discuss the kindness and greatness and power of God along with the process of rain. Verse SV. Final, XX.1802 clearly mentions the creation of oceans, rivers etc. due to the heavy rain by God.

असावि सोमो अरुषो वृषा हरी राजेव दस्मो अभि गा अचिक्रदत् ।

पुनामो वारमत्येष्यव्ययं श्येनो न योनि घृतवन्तमासदत् ॥ SV. Previous,V.562 ॥

आ पवमान सुष्टुति वृष्टि देवोम्यो दुवः ।

इषे पवस्व संयतम् ॥ SV.Final,V.906 ॥

त्व सिन्धू खासृजोधराचो अहन्नहिम् ।

अशत्रुरिन्द्र जज्ञिसे विश्वं पुष्यसि वार्यम् ।

तन्त्वा परि ष्वजामहे नभन्तामन्थकेषां ज्यांका अधिधन्वसु ॥ SV.Final,XX.1802 ॥

In Atharva Veda we come across the similar concepts and hydrologic knowledge as contained in the other Vedas. Verse (I,4.3), for example, states as:

अपो देवी रूपं हवये यत्र गावः पिवन्त नः ।
सिन्धुभयः कर्त्तुं हविः ॥ AV.I,4.3 ॥

This verse reveals the concept of evaporation due to heating by Sun rays and subsequently life giving rainfall. The Prithvi Sukta of the Atharva Veda (XII,1.51) speaks of a violent dusty storm which uprooted trees and calls it as मातरिश्वाः

यां द्विपादः पक्षिणः संपतन्त हंसाः सुपर्णाः शकुना वयांसि ।
यस्यां वातो मातरिश्येयते रजांसि कृण्वंच्यावयंश्च वृक्षान् ।
वातस्य प्रवामुपवामनु वात्यर्चिः ॥ AV.XII,1.5 ॥

The various hymns of the Rig Veda indicate that the Vedic literature mythically describes the Indian atmospheric phenomena, especially those of the monsoons and rainy season, and the violent thunderstorms by which they are usually accompanied.

Following the Rig Veda, the Satpatha Brahmana also recognizes sixty three winds (SB Part I, 2.5.1.13). The same text calls hoar frost as पृश्वा.

त्रिः प्रष्टत्वा मरुतो वावृधाना उस्त्रा इव राशयो यज्ञियासः ।
उप त्वेमः कृधि नो भागधेयं शुष्मं त एना हविषा विधेम ॥ RV.VIII,96.8 ॥

The Taithiriya Aranyaka (I.9.8) says that there are seven types of air currents or winds in the atmosphere which produce seven types of clouds of the same appellation. These are (1) वराहव (2) स्वतपस (3) विधुन्महस (4) धूपम (5) श्वापय (6) गृहमेघ and (7) आशिमिविद्विष. The वराहव creates circumstances which are responsible for condensation and good rainfall. The स्वतपस is that whose temperature condition is little affected by the insolation or Sun and perhaps occurs at a higher altitude and is responsible for precipitation. The actual text of the mantra is as follows:

तातनुक्रमिष्यायः वरावस्स्वतपसः		विधुन्मय सो धूपयः ॥
श्वापयो गृहमेघाश्चेत्येते		पे चेमेशिमिविद्विषः ।
पर्जन्यास्सप्त पृथिवीममि वरषन्ति		वृष्टमिरति ॥ Tai.Ara.,I,9.8 ॥

The विधुन्महस gives rise to thunderstorm; the धूपय possesses some latent property or aroma which it imparts to the objects with which it comes in contact, expanding quickly and the गृहमेघ affects the humidity or moisture content of the atmosphere. These six belong to a single genus and have

a single or similar region of activity. The आशिमिदिद्विष belongs to another genus and its geographical realm or region is different from the preceding six; however, it is highly favourable for agricultural purposes. These seven classes of clouds bring rainfall with seven types of winds. In verse I.10.9 of the Taithiriya Aranyaka, two more types of clouds are mentioned (Tai,Ara,I,10.9). These are: (1) शम्बर or शाम्बर and (2) बहुसोमगी. The former is responsible for profuse rainfall, and the later is identified to be “the moving nimbus fall of water”. Thus, total nine types of clouds with their properties, have been identified in the Taithiriya Aranyaka.

सवितारं वितन्वन्तम् । अनुवध्नाति शाम्बरः । आपपूरषम्बश्चैव ।

सवितारेपसोभक्त ॥ I,10.8 ॥ त्वं सुतप्तुं विदित्वैव ।

बहुसोमगीरं वशी ॥ अन्वेति तुयोवाक्रियां तम् । आ यसूयान्शसोमतृप्सूषु ॥ Tai,Ara,I,10.9 ॥

On the similar lines, during the age of epics we get information regarding clouds, rainfall, evaporation, snow, storms etc. Verse VII.4.3 of Ramayana speaks of three kinds of clouds - ब्राह्म (Produced from Brahma), अग्नेय produced from fire and पक्षज (produced on a mountain flank). White, red, blue and grey clouds are also referred to in the epic (V.1.81) as:

पाण्डुरास्णवर्णानि नीलमाज्जिमिष्टकानि च ।

कपिना कष्यमाणानि महाभ्राणि चकाशिरे ॥ Ramayana V,1.81 ॥

हरितास्णवर्णानि महाभाणि चकाशिरे ॥ Ramayana V,57.7 ॥

Climatic vagary or absence of rainfall is referred to in Ramayana (I.9.9) as:

अनावृष्टिः सुघोरा वै सर्वलोकभयावहा ॥ Ramayana I,9.8 ॥

अनावृष्ट्यां तु वृत्तायां समानीय प्रवक्ष्यति ॥ Ramayana I,9.9 ॥

Here, it speaks indirectly of atmosphere free from dust, fog, frost and mist. Similarly, the condition of nocturnal sky (the moon from नीहार or mist) is alluded to in Ramayana (I.29.25), as:

शशीव गतनीहारः पुनर्वसुसमन्वितः ॥ Ramayana I,29.25 ॥

Mist and its disappearance through diurnal rise of temperature is referred to in I,55.25 verse of Ramayana, mist and severe cold in III, 16.12, cold western wind made still colder due to the effect of him (frost) in III, 16.15, very dense mist in the vicinity of earth surface in III, 16.23,

water vapour hanging on the surface of the river structure in III.16.24, dew formation on the sandy margins of the bank in III,16.24 and snowfall in III,16.25. These verses are given here as:

वदतौ वै वसिष्ठस्य या भैरिति मुहुर्मुहुः ।

नाशायाम्यघः गाधेयं नीहारमिव भास्करः ॥ Ramayana I,55.25 ॥

निवृत्ताकाशशयनाः पुष्यनीता हिमारुणाः ।

शीतवृद्धतरायामास्त्रियाना यान्ति साम्प्रतम् ॥ Ramayana III,16.12 ॥

प्रकृत्या शीतलस्पर्शो हिमविद्वश्च साम्प्रतम् ।

प्रवाति पश्चिमो वायुः काले द्विगुणशीतलः ॥ Ramayana III,16.15 ॥

अवश्यायतमोनद्धा नीहारतमसावृताः ।

प्रसुप्ता इव लक्ष्यन्ते विपुष्या वनराजयः ॥ Ramayana III,16.23 ॥

वाष्पसंक्षन्नसलिला रुतविज्ञेयसारसाः ।

हिमद्रिवालुकैस्तीरैः सरितो भान्ति साम्प्रतम् ॥ Ramayana III,16.24 ॥

तुषारपतनाच्चैव मृदुत्वाद् भास्करस्य च ।

शैत्यादगाग्रस्थमपि प्रायेण रसवज्जलम् ॥ Ramayana III,16.25 ॥

Verse IV,1.15 of Ramayana states about the mountain winds. In another Verse (VI, 78.19) we read about dusty, dry and gusty wind. Later on violent storm or tornado is also mentioned in Ramayana (VI,106.21, वाता मण्डलिनस्तीवाः).

शैलकंदर निष्क्रान्तः प्रगीत इव चानिलः ॥ Ramayana IV,1.15 ॥

Like the Ramayana, the epic Mahabharata also contains valuable information related to hydrosiences. In the twelfth skanda of the epic, atmosphere is divided into seven regions (skanda, sphere, XII,328.31) and are discussed in considerable detail as “that wind which is the first in above number and which is known by the name of प्रवह drives, along the first course, masses of clouds born of smoke and heat. Thus, during this time, the constituents of cloud were also predicted. This wind passes through the sky and comes into contact with water in the clouds (MB.XII,328.36) as:

पृथिव्यायन्तरिक्षे च यत्र संवान्त वायवः ।
सप्तैते वायुमार्गा वै तान् निवोधानुपूर्वशः ॥ MB.XII,328.31 ॥

प्रेरयत्यभ्रसंधातान धूमजांश्चोष्मजांष्व यः ।
प्रथमः प्रथमे मार्गे प्रवहो नाम योनिलः ॥ MB.328.36 ॥

The second wind called आवह, blows with a loud noise (MB. XII329.37). The wind which drinks up water from the four oceans and having sucked it up, gives it to the clouds, presents them to the Gods of rain, is the third in number and is known as उत्त्वह (MB. XII328.38-39-40).

अम्बरे स्नेहमम्येत्य विधुदभयश्च महाघुतिः ।
आवहो नाम संमवाति द्वितीयः श्वसनो नदन् ॥ MB.XII,328.37 ॥

उदयं ज्योतिषां शश्वत सोमादीनां करोति यः ।
अन्तर्देहेषु चोदानं यं वदान्त मनीषिणः ॥ MB.XII,328.38 ॥

यश्चतुर्भयः समुद्रेभ्यो वायुर्धारयते जलम् ।
उद्वत्याददते चापो जीमूतेभ्योम्बरे बिल ॥ MB,XII,328.39 ॥

योदिभः संयोज्य जीमूतान पर्जन्याय प्रथच्छति ।
उत्त्वतो नाम बहिष्ठस्तृतीयः स सदागतिः ॥ MB,XII,328.40 ॥

The winds which support the clouds and divides them into various parts, which melts them for pouring rain and once more solidifies them, which is perceived as the sound of roaring clouds, is known by the name संवह. Fifth layer is called विवह and the sixth is referred to as परिवह. The seventh called परावह (MB.XII.328.41-42-43-47-48) refers perhaps to some cosmic region.

समूहयमाना बहुधा येन नीताः पृथक् घनाः ।
वर्षमोक्षकृतारम्भास्ते भवन्ति घनाघनाः ॥ M.B.XII,328.41 ॥

संहता येन चाविद्धा भवन्ति नदतं नदाः ।
रक्षणार्थाय सम्भूता मेघत्वमुपयान्ति च ॥ M.B.XII,328.42 ॥

यो सौ वहति भूतानां विमानानि विहायसा ।
चतुर्थः संवहो नाम वायुः स गिरिमदिनः ॥ M.B.XII,328.43 ॥

दारुणोत्पातसंचारो नभसः स्तनयितुमान् ।

पञ्चमः स महावेगो विवहो नाम मारुतः ॥ M.B.XII,328.48 ॥

षष्ठः परिवहो नाम स वायुर्जयतां दरः ॥ M.B.XII,328.45 ॥

येन स्पृष्टः पराभूतो यात्येव न निवर्तते ।

परावहो नाम परो वायुः स दुरतिक्रमः ॥ M.B.XII,328.52 ॥

Here, at five places, the term wind used, actually implies a sphere or layer. These five names also occur in Puranas and other later literature. The epic gives another classification of clouds also giving four classes of clouds. The four types of clouds are संवर्तक, वलाहक (MB,VIII,34.28), कुण्डधार (XII 271.6) and उत्तंक (MB XIV 55.35-36-37). The वलाहक clouds are formed in the विवह layer of atmosphere (described before). The clouds bringing rainfall in desert area are called उत्तंक. These classification of clouds are different from those enumerated in Ramayana and Puranas.

सोथ सौम्येन मनसा देवानुचरयन्तिके ।

प्रत्यप्स्यज्जलधरं कुण्डधारमवस्थितम् ॥ MB,XII,271.6 ॥

तदा मरौ भविष्यन्ति जलपूर्णाः प्योधराः ।

रसवच्च प्रदास्यन्ति तोयं ते भगुनन्दन,

उत्तक्कुमेघा इत्युक्ताः ख्याति यास्यन्ति चापि ते ॥ MB,XIV,55.36 ॥

Around 600-700 BC, Kanada in his Vaisesika Sutra referred to the process of condensation and dissolution of water (Vais. Sutr.V,2.8). He remarks “condensation and dissolution of water is due to the conjunction with fire or heat”. About the phenomena of thunder, he observes that the “rolling of thunder is a mark of the ingress of the light of the sky (Vais. Sutr.V,2.9)”, i.e. it is the peeling of thunder which warrants the inference. He again says (Vais. Sutr. V, 2.11) that the rolling of thunder results from conjunction with water and disjunction from a cloud. Here, it is fully evident that the great sage knew that thunder is caused due to impact of positively and negatively charged clouds.

अपां सङ्घातो विलयनञ्च तेजः संयोगात् ॥ Vais. Sutr.V,2.8 ॥

तत्र विस्फूर्जं धुर्लिङ्गम् ॥ Vais. Sutr.V,2.9 ॥

अपां संयोगाद्विभागाच्च स्तनयित्नाः ॥ Vais. Sutr.V,2.11 ॥

Discussing the falling of raindrops and flowing of streams, he further presents causes of falling of water resulting from gravity in the absence of conjunction (Vais. Sutr.V,2.3) i.e. falling of water in the form of rain, has gravity as its non-coinherent cause.

अपां संयोगाभावे गुरुत्वात् पवनम् ॥ Vais. Sutr.V,2.3 ॥

In the verse V, 2.4, it has been said that the distant progression of the stream or great aqueous whole composed by mutual conjunction of the fallen waters or raindrops, is produced by fluidity as its non-coinherent cause and by gravity as its efficient cause.

द्रवत्वात् स्यन्दनम् ॥ Vais. Sutr.V,2.4 ॥

The phenomena of evaporation, cloud formation, classification of clouds and their relationship with winds or regions of atmosphere (वातस्कन्ध) are also quite satisfactorily discussed in several Puranas (Vayu Chapter 51, Linga Vol.I, Chapt. 36, Matsya Vol.I, Chapt. 54). Describing the general genesis of clouds, the Vayu Purana (51.22-25) says that there is moisture content in all the movable or immovable objects of the world and due to insolation or Sun's rays, evaporation of that humidity takes place, and this process produces clouds. viz.

आर्क तेजोहिभूतेभयोहयादत्ते रश्मिमर्जलम् ॥ Vayu,51.23 ॥

मेघानां पुनरुत्पत्तिस्त्रिविधा योनिरुच्यते ।

अग्नेया ब्रह्मजाश्चैव वक्ष्यामि पृथाविधाः ।

त्रिधा घनाः समाख्यातास्तेषां वक्ष्यामि संभवम् ॥ Vayu 51.28 ॥

अग्नेयास्त्वर्णजाः प्रोक्तास्तेषां तस्मात्प्रवर्तनम् ।

शीत दुर्दिनवाता ये स्वगुणास्ते व्यवस्थिताः ॥ Vayu 51.29 ॥

जीमूता नाम ते मेघा येभ्यो जीवस्य संभवाः ।

द्वितीयं प्रवहं वायु मेघास्ते तु समाश्रिताः ॥ Vayu 51.36 ॥

The above verses say that those clouds which give or sprinkle water are called मेघ and which do not bring any rainfall are known as अभ. There are three types of clouds (1) आग्नेय (2) ब्रह्मज (3) पक्षज. These are connected with cyclonic (thermal and insolational), convectional (occurring in northern continents, Siberia and equatorial regions) and orographic (occurring and proceeding

from mountain flanks) types of rainfall respectively. According to above mentioned Puranas, आग्नेय occurs in the winter season and it is devoid of lightening and thunder and is of immense expanse and found in the mountain foots also. It brings rainfall within a radius of a mile or two. This description approximates most to the Nimbus of modern days. The Brahmaja (ब्रह्मज) clouds are produced due to convection currents. In precipitation they cover an area of radius of nearly a yojana (five or eight miles). Most probably these are cumulonimbus. The Puskara-Vartaka (पुष्करावर्त) clouds originate from or in the wings of mountains (पक्षसंभवा). They assume various forms and produce deep rumbling sound. They are full of profuse water and bring excessive rainfall which is extremely destructive. This description conforms to a large extent to the modern class of altostratus.

The Matsya Purana (Vol.I, Chap.54) furnishes still more elaborate and scientific information regarding clouds. It says that the clouds जीमूत is the cause of life. These clouds remain suspended on the air called Avaha. They change shape and goes up a yojana, from there form into rain hence they are called the source of rain (Verse 10). If the shlokas 17,18 and 19 are interpreted symbolically, they give other four classes of clouds expressed by the nomenclature गज, पर्वत, मेघ and भोगी. Then in the Verse 17 can be recognized further four classes of गज clouds.

विषुवद्गहवर्णश्च सर्वमेतद् ध्रुवेरितम् ।

जीमूता नाम ते मेघा यदेभ्यो जीव सम्भवः ॥ Matsya,I,54.9 ॥

द्वितीय आवहन वायुर्मैघास्ते त्वभिसंश्रिताः ।

इतोयोजनमात्राच्च अध्यर्द्धविकृता अपि ॥ Matsya,I,54.10 ॥

तेषामप्यायनं धूमः सर्वेषामविशेषतः ।

तेषां श्रेष्ठश्च पर्जन्यश्चत्वारश्चैव दिग्गजाः ॥ Matsya,I,54.17 ॥

गजानां पर्वतानाञ्च मेघानां भोगिभिः सह ।

कुलमेकं द्विधाभूतं योनिरेका जलं स्मृतम् ॥ Matsya,I,54.18 ॥

Parjanys (पर्जन्य) and दिग्गज rain in the season of हेमन्त and they are very useful for agricultural growth is spoken in the verse below:

पर्जन्यो दिग्गजाश्चैव हेमन्ते शीतसम्भवम् ।

तुषारवर्ष वर्षान्ति वृद्धां ह्यन्नविवृद्धये ॥ Matsya,I,54.19 ॥

Process of condensation and precipitation on hygroscopic nuclei are very carefully described in a nutshell in the Matsya Purana (I,54.33) as:

नियच्छत्यापो मेघेभवः शुक्लाः शुक्लैस्तुरश्मिभिः ।

अभ्रस्थाः प्रयतन्त्यापोवायुनासमुदीरिताः । Matsya,I,54.33 ॥

Meaning: “the waters from the (vapours) of the clouds when brought into contact with the wind (namely hygroscopic content of the air) fall in the shape of rain”.

The Vishnu Purana (II,9.11-12) very scientifically enumerates the four sources of atmospheric moisture, “the glorious Sun, O Maitreya, exhales moisture from four sources, namely – seas, rivers, the earth and living creatures,” viz.

अभ्रस्था प्रपतन्त्यापो वायुना समुदीरिताः ।

संस्कारं कालजनितं मैत्रैयासाघ निर्मलाः ॥ Vishnu,II,9.11 ॥

सरत्ससमुद्रभौमास्तु तथापः प्राणिसम्भवाः ॥

चतुष्प्रकाश भगवानादन्ते सविता मुने ॥ Vishnu,II,9.12 ॥

The celebrated poet Kalidasa (100 B.C.) also knew a lot about clouds and the allied phenomena. He defines cloud thus “it is an assemblage of smoke, electricity, water and air” (Purvamegha Verse 5). At other places (Purvamegh, Verse 6) the poet names two types of clouds namely पुष्कर and आवर्तक

धूमज्योतिः सलिलमरुतां सन्नपातः क्व मेघः ।

सन्देशार्था क्व पटुकरणैः प्राणिभिः प्रापणीयाः ॥ Meghadutam,Purvamegha.5 ॥

जातं वंशे भुवनविदिते पुष्करावर्तकानां जानामि त्वां प्रकृतिपुरुषं कामरुपं मघोनः ॥ Purvamegha Verse 6 ॥

The Mricchakatika (600 AD) refers to a kind of cloud द्रोण (X.26) from which the rain streams forth as from a bucket. In another context, the famous drama refers to a special type of rain द्रोणवृष्टि streaming forth as from a trough (X.39) viz.

कोयमेवविधे काले कालपाशास्थिते मयि ।

अनावृष्टिहते सस्ये द्रोणमेघं इवोदितः ॥ Mricchakatika, X.26 ॥

केयमभयुघते शस्त्रे मत्युवक्त्रगते मयि ।

अनावृष्टिहते सस्ये द्रोणवृष्टिरिवागता ॥ Mricchakatika, X.39 ॥

Four types of clouds in all have been spoken of by Kalidas. They are आवर्त, संवर्त, पुष्कर and द्रोण. The Avarta brings no rainfall; the Samvarta gives an abundance of rain, the Puskara causes flood of rain and the Drona is most congenial to agriculture and mankind. This is stated in nutshell in the following lines –

आवर्तो निर्जलो मेघः संवर्ततश्च वहूदकः ।

पुष्करो दुष्करजलो द्रोणः शस्यप्रपूरकः ॥

Kalidas Granthavali, Abhidhan Kosh, P.154 ॥

In the library (Saraswati Bhavan Pustakalaya) of Sampurnanand Sanskrit University, Varanasi a manuscript treatise entitled as मेघमाला is available. As the very name suggests, it is a work on climatology and more specifically science of clouds. On the basis of content and style of dialogue Tripathi (1969) tried to establish that Meghamala is a part of रुद्रायमालतंत्रम् (around 900 AD around). मेघमाला has 11 chapters. The first chapter of मेघमाला opens with the enquiry

मेघस्तु कीदृशादेव कथं विद्युत्प्रजायते ।

कीदृशं वर्णरूपं तु शरीरं तस्य कीदृशम् ॥

(Meghamala, Manuscript No. 37202, Sampurnanand Sanskrit University, Varanasi)

The first chapter deals with what are clouds, how lightning is produced, what are nature, texture, ingredients and colours of clouds. Later in the Verse 20,21,22 is expressed, in their conventional Indian style, that the mountains control clouds. From Verses 32 to 68 we gather that there is a larger division of clouds comprising twelve species and designated as 1. सुबुध 2. नन्दशाला 3. कन्यद 4. पथुश्रवा 5. वासुदी 6. तक्षक 7. वकर्त 8. सारवत 9. हेमकाली 10. जलेन्द्र 11. वज्रदंष्ट and 12. विष्णुप्रभ. But no scientific detail of these is furnished. The Chapter II enumerates various types of years, refers to their rainfall and discusses the economic characteristics or conditions of each of them. The IIIrd chapter dwells on astrological influence on rainfall, climatology and economic condition of people, state of plenty and scarcity and production of various crops. VIIIth chapter aspires to

discuss the nature of rainfall and other meteorological conditions in the twelve months of the year. About the Kartika (October – November) the author says that during this month scattered clouds of varied colours occur. In Pausa (December – January) if sky is over cast with clouds, it is a very good symptom. If the month of Magha (January – February) is not normally cold (or has no frost) there occurs scanty rainfall in Phalaguna (February – March) northeast wind brings good downpour.

मासि मासि कथं देवि कीदृशं गर्भलक्षणम् ।
किं वातं किं घनं युक्तं कस्य कालेन वर्षति ॥

कार्तिके शुक्ल नन्दायां पञ्चरूपाणि यो भवेत् ।
अभ्राणि श्वेतवर्णानि रक्तवर्णानि यो भवेत् ॥

पतिवर्णानि यो मेघा हि कृष्णवर्णश्च भवेत् ।
कांस्यवर्णो भवेद्यस्तु ताम्रवर्णस्तथा भवेत् ॥

न माघोपतितं शीतं ज्येष्ठे मूलं न वृष्टिकृत् ।
नार्दायां पतितं तोयं दुष्टकालस्तदा भवेत् ॥

तदा देवि भविष्यन्ति सुभिक्षं क्षेमवेव च ।
पूर्वोत्तरजवातेन रात्र्यन्ते जलमुत्तम् ॥ Meghmala, Page 14-38 ॥

In the chapter IX of Meghmala there is discussion on clouds, winds and lightning. Firstly, it discusses the correlation of rainfall with different shapes and directions of lightning. Then we are told that north-east wind is conducive to prosperity, southerly does good to people, south-west wind causes misery, westerly is much beneficial for the higher production of rice, northerly is also favourable to the good of people, and it produces a condition of plenty.

पूर्वे विधुत्करामेघा अग्नियां जलशोषिणी ।
दक्षिणे रौरवं घोरं नैऋत्यां तापमादिशेत् ॥

शुभिक्षं पूर्ववातेन जायते पात्र संशयः ।
दक्षिणे तु क्षेमकरो नैऋत्यां दुः खदो भवेत् ॥

वारुण्यां दित्यंधान्यानि वायत्यांवायुखे भवेत् ।
उत्तरे शुभदो देवि ऐशान्यां सर्वसम्पदः ॥ Meghmala, Page 47-48 ॥

The chapter X of Meghmala deals with the propitiation of clouds and apart from repeating the twelve species of clouds, already mentioned, adds another classification of the same comprising seven species designated as अम्बुद, गोलक, गिरि, आरोपक, सपर्वत, खिखिन्द and कोटिवार.

The encyclopedic Tantrik literature also does not lag behind in supplying information on hydrology. From the Tantraloka of Abhinavagupta, we can find out some important climatological and meteorological facts. In its Ahnika designated as देशाध्वप्रकाशन are described winds, clouds, track of winds and the allied phenomena (Vol. V of the Tantraloka) (Tripathi, 1969). It refers to ten air channels (वायुपथ) which are perhaps peculiar to only this text. Those ten air channels are 1. वितव 2. ऋतार्द्धि 3. वज्राइक, 4. वैद्युतं 5. रैवत 6. विषावर्त (दुर्जय) 7. परावह 8. आवह 9. महावह and 10. महापरिवह (Vol. V, 121.138). These are arranged in space according to increasing height. The outstanding Tantrik work recognized ten types of clouds 1. मूकमेघ 2. प्राणिवर्षी 3. विषावर्षी 4. स्कान्द 5. संवर्त 6. ब्राह्म 7. पुष्कर 8. जीमूत 9. ईशकृत, and 10. महेशिकृत (कपालोत्थ). These types also occur according to the increasing height. It is perhaps for the first time in Indian literature that establishes the height of clouds. It reveals that different clouds occur at different level in the atmosphere.

The Jain literature also made a considerable contribution in the field of meteorology. The 'Prajnapana' and 'Avasyaka Curnis' provide outstanding references to the various types of winds (Tripathi, 1969). The Avasyaka Curnis furnish a list of fifteen winds (9-7/913) as: 1. प्राचीनवात (easterly) 2. उदीचीन (northerly) 3. दक्षिणवात (southerly) 4. उत्तर पौरस्त्य (northerly blowing from the front) 5. सवात्सुक (undefined) 6. दक्षिण पूर्वतुंगर (southerly strong wind) 7. अपरदक्षिणबीजाय (blowing from the south-west) 8. अपरबीजाय (westerlies) 9. अपरोत्तगर्जन (north-westerly hurricane) 10. उत्तरसवात्सुक (unknown) 11. दक्षिण सवात्सुक 12. पूर्वतुंगर 13. दक्षिण and पश्चिम बीजाय 14. पश्चिमगर्जभ (western storm) 15. उत्तरीगर्जभ (northern storm). Later in the same continuation tornadoes are referred to as कालिकावात. This vocabulary had influenced the Arabian geographers and navigators and they readily absorbed several of these Indian technical terms in their own language (Motichandra, 'Sarhavaha' (Hindi), P.202).

The 'Prajnapana' also refers to snowfall (हिम) and hailstorm (करक) (I.16). The 'Trilokasara' (Passage 679, P.280) of Nemichandra says that there are seven types of कालमेघ (periodic clouds). They rain for seven days each in the rainy season. Then there are twelve species of white clouds

designated as द्रोण. They also bring rain for seven days each. Thus, the season of rainfall extends over 133 days in all.

The Buddhist literature also throws significant light on meteorology. In the narrative of the first Jataka, named 'Apannaka', several climatological facts are described. In 'Migalopajataka' (Cowel, Eng. Trans. Vol.III, P.164.), two violent storms are mentioned as कालवात (black wind) and बेरम्बरात (Tripathi, 1969). The latter is said to belong to the upper air (Samyutta Nikaya, Eng. Trans. XVII. 1-9, P.157). The Sumeru mountain was frequently visited by a violent hurricane (उत्पाटनवात or हरणवात) (Mahamorajataka No. 491, P.333; Harit Jataka No. 431, P.497). It resembled whirlwind in movement. In 'Milinda Panho' hot wind or Loo is spoken of as वातातप (Eng. Trans. Vol.II,IV,6.35, P.86). 'Aryasura' names four types of winds नियतानिल (Monsoon), चण्डानिल (tempest), उत्पातवात (hurricane) and पश्चात्यवायु (westorlies) (Jatakamala, ed. by H. Kern, 10.29, P. 90, 127, 133). In the 'Vinaya Pitaka' (III, V.9.4,P.85), whirlwind is called वातमण्डलीका. The Divyavadana' speaks of some kinds of hurricane as कालिकावात (Vol.II,P.41), and of storm accompanied by rain as वातवर्षम (Vol.II,P.163).The 'Milindapanho' (IV.1.36) says that there are four types of rainfall: 1. of rainy season 2. of winter season, 3. of the two months आषाढ़ and श्रावण (July and August), and 4. rain out of season. At a glance, it can be seen that the classification is fully scientific.

The Buddhist literature refers to two general classes of clouds as: कालमेघ (monsoon cloud) and अकालमेघ (storm clouds or accidental ones) (Mahavastu Vol.II, P.34, Tripathi, 1969). The Samyutta Nikaya classifies clouds into five categories (Vol.III, Book XI, 32.1.1, P.200), 1. शीतवलाहक (cool clouds), 2. ऊष्णवलाहक (hot clouds) 3. अम्रवलाहक (thunder clouds, it can be identified with cumulus), 4. वातवलाहक (wind clouds – perhaps clouds formed due to the activity of convection current in the atmosphere) and 5. वर्षवलाहक (rain clouds – most probably cumulonimbus which brings copious downpour of rain).

Thus, we see that the Jain and Buddhist texts (before 400 B.C.) have a very scientific classification of clouds and winds that can be compared with the modern meteorology. So much of subtle observation at such an early date is a golden achievement of ancient times.

Variation of Rainfall

According to the Matsya Purana, to the north and south of the snow-clad mountains (हिमवत) occurs the पुण्ड्र cloud which greatly increases the stock of rain. All the rain formed there converts itself into the snow. The wind on the हिमवत draws by its own force those snow flakes and pours them on the great mountains. Beyond the हिमवत there occurs little rain (Matsya, I,54.22-25).

शकीरान सम्प्रभुज्वन्ति नीहार इति स मृतः ।

दक्षिणेन गिरिर्योसौ हेमकूट इति स्मृतः ॥ Matsya,I,54.22 ॥

उदगहिमवतः शैलस्योत्तरे चैव दक्षिणे ।

पुण्डं नाम समाख्यात सम्वगवृष्टि विवृद्धये ॥ Matsya,I,54.23 ॥

तस्मिन् प्रवर्तते वर्षं तन्तु षारसमुद्रभवम् ।

ततो हिमवतो वायुर्हिमं तत्र समुद्रभवम् ॥ Matsya,I,54.24 ॥

आनयत्यात्मवेगेन सिञ्चियानो महागिरिम् ।

हिमवन्तमतिक्रम्य वृष्टिशेषं ततः परम् ॥ Matsya,I,54.25 ॥

Thus, there is a reference to a very important geographic fact of scanty rainfall or arid condition of the Tibetan plateau. The study and knowledge of this fact is really creditable on the part of those ancient Indians. The Linga Purana (Vol. I,36.38.39 and 49) says “it is the प्रवह wind or air current which makes the clouds produced by smoke and thermal activity full of water, so that the clouds Puskara (पुष्कर) and पक्षज give copious rainfall”.

दन्दह्ययमानेषु चराचरेषु गोधूमभूतास्त्वथ निष्क्रमन्ति ।

या या ऊर्ध्वं मारुतेनेरिता वै तास्तास्त्वभ्रांयाग्निनावायुना च ॥ Lings,I,36.38 ॥

अतो धूमाग्निवातांनां संयोगस्त्वमुच्यते ।

वारीणि वर्षतीत्यभ्रमभ्रस्येशः सहस्रत्रदृक् ॥ Linga,I,36.39 ॥

विरिचोच्छ वासताः सर्वे प्रवहस्कंधजास्तः ।

पक्षजाः पुष्कराघश्च वर्षाति च यदा जलम् ॥ Lings,I,36.49 ॥

Modern meteorology tells us that polar winds actually never bring any rainfall in the year in the region under their influence – flanking poles or Tundra, and only scanty summer rain occurs in those areas due to the sweeping of strong westerlies. The same fact is stated in the Puranic line,

ध्रुवेणाधिष्ठितो वायुर्विष्टिं संहरते पुनः ॥ Matsya, Vol.I, 54.36 ॥

Meaning: the air from the Pole drives away the rain,

The Vrhata Samhita and Mayuracitraka by Varahamihira are two very important treatises which are replete with climatological and meteorological information. Although they abound in astrological guesses, they contain sufficient scientific facts also. In the Vrhata Samhita, there are three chapters (21st, 22nd, and 23rd) on climatology and meteorology and they treat the subject in their own ancient conventional style. Here only the salient features of the chapters are being presented.

The verses 23 and 24 of the chapter 21 of Vrhata Samhita state that extremely white or dark clouds resembling aquatic animals like huge fish, shark or tortoise and seen before the rainy season are a source of abundant rainfall viz.

मुक्तारजतनिकाशास्तमालनीलोत्पलज्जनाभासः ।
जलचरसत्त्वाकारा गर्भेषु घनाः प्रभूतजलाः ॥ Vr.S.21.23 ॥

तीव्रदिवाकरकिरणाभितापिता मन्दमारुता जलदाः ।
रुषिता इव धाराभिर्विसृजन्त्यम्भः प्रसवकाले ॥ Vr.S.21.24 ॥

The verse 31 discusses the conditions or meteorological ingredients which determine the spatial expanses of rainfall, though it appears to be of little value from modern meteorological point of view.

पञ्चनिमित्तैः शतयोजनं तदर्द्धार्द्धमेकहान्यातः ।
वर्षति पञ्चनिमित्ताद्रूपेणैकेन यो गर्भः ॥ Vr.S.21.31 ॥

From chapter 22, it is gathered that fleecy and thick clouds give abundant rainfall which is very congenial to agriculture. Again, if clouds situated in the east, south and north sail towards south, west and north respectively, they cause fine and copious rainfall.

रविचन्द्रपरीवेषाः स्निग्धा नात्यन्तदूषिताः ।
वृष्टिस्तदापि विज्ञेया सर्वसस्यार्थसाधिका ॥ Vr.S.22.7 ॥

मेघाः स्निग्धाः संहताश्च प्रदाक्षिणगतिक्रियाः ।
तदा स्यान्महती वृष्टिः सर्वसस्याभिवृद्धये ॥ Vr.S.22.8 ॥

In the Mayuracitraka, it is stated that scattered clouds devoid of lightning are harmful to people and those of red and white silken or golden or Kraunca bird's hue, embedded in the atmosphere and fleecy in texture are always beneficial to the people. Causation of fog or mist in Pausa (December–January) is conducive to good rainfall. (Sampurnanand Sanskrit University, Library, Manuscript No. 34332, Page 36-37).

पौषस्य कृष्णसप्तम्यां नभो विमलतारकम् ।
स्वात्यां तुषारपातः स्यात् श्रावणे तत्र वर्षणम् ॥

Discussing the conditions determining rainfall, it says that if there is no frost in Magha (January–February), no vigorous wind in Phalguna (February – March), no clouds in Chaitra (March–April), no hailstorm in Vaisakha (April–May) and no scorching heat in Jyestha (May–June), there is insufficient rain in the rainy season (Above manuscript, Page 17 -18), viz.

माघे हिमं न पतति वाता वान्ति न च फाल्गुने ।
न च धूमायितं चैत्रे घनैर्नभस्ततं न तु ॥

कारका मोच न वैशाखे शुक्रे चण्डातपो न हि ।
तदातितुच्छा वृष्टिः स्यात् प्रावृष्टकाले न संशयः ॥

If Sun is hot in the morning, its light during the day is of yellowish hue and clouds are fleecy and dark-coloured, the conditions result in good rain. Similarly, if the Sun is hot in the morning or at the time of rising and scorching at noon and clouds have a pigment of molten gold, rain occurs during the very day (above manuscript, Page 18).

प्रावृटकाले यदा सूर्यो मध्याह्ने दुः सहो भवेत् ।
तद्दिने वृष्टिदः प्रोक्तो भृशं स्वर्णसमप्रभः ॥

If water appears to be dull, clouds are of the shape of mountain, quarters are clear, the sky is of the hue of crow's egg, there calm in the atmosphere and aquatic animals like high and others disappear in the bottom and grogs make loud noise, very fine and copious rainfall comes soon (Manuscript No. 34332, Page 18). Further, if the texture of the clouds resembles the wings of a Partridge, rainfall occurs.

यदा जलं च विरस गोनेत्र सन्निभिः ।
दिशश्च विमलाः सर्वाः काकाण्डाभं यदा नभः ॥

न यदा वाति तपनः पवनः स्थलं यदा ।
शब्दं कुर्वन्ति मण्डूकास्तदा स्याद् वृष्टिकत्तमा ॥

Thus, it is evident that Mayuracitraka has attempted to formulate principles for forecasting rainfall variation through the observation of natural phenomena and the synchronization and co-relationship of the two. The symptomatic synchronization in the realm of nature is often governed by laws having mathematical accuracy in which intuition of the animate (birds and the animals) and scientific cause and effect relationship of events form the accurate base, provided the observation has been made very carefully. In those ancient days, when advanced meteorology and its complicated computations, computers and other cybernetics and servo-mechanic contrivances were unknown, this was of special significance and most probably the only method.

Measurement of Precipitation

The amount of precipitation in the form of rain is usually determined from the accumulation of water collected in a rain gauge; and several types of recording instruments are routinely employed for the purpose. There are strong proofs to establish that the system of measuring rainfall was introduced by the Mauryan rulers in the Magadha country (south Bihar) in the fourth or third century B.C. and they are credited with the establishment of first observatory. The system was continued to be practised effectively by the succeeding rulers until the end of the sixth century A.D. (Srinivasan et al., 1975).

During the Mauryan period, the raingauge was known as वर्षमान. Kautilya describes its construction in these words “In front of the store house, a bowel (Kunda) with its mouth as wide

as an aratni (24 angulas = 18” nearly) shall be set up as raingague (वर्षामान) (Arthasastra, Book II, Chapt. V, P.56 Shamasastri). A schematic of the modern raingauge is shown in Figure 3.2. By comparing the dimensions of the ancient Indian and Symon’s raingauge, one can easily infer about the level of knowledge possessed during that period.

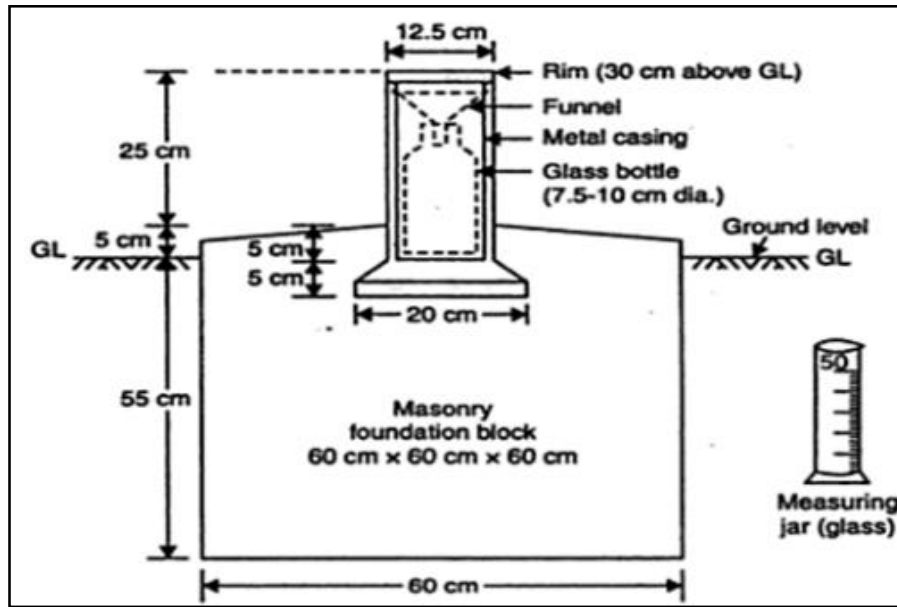


Figure 3.2: The Symon’s raingauge (Modern raingauge) (Source: Raghunath, 2006)

The distribution of rainfall in various areas was well known at that time. A reference from Kautilya’s Arthshatra can be cited here as: “The quantity of rain that falls in the country of *jangiila* (desert countries or countries full of jungles) is 16 *dronas*; half as much more in *anupanam* (moist countries); as the countries which are fit for agriculture (*desavapanam*); 13.5 *dronas* in the countries of *asmakas* (Maharashtra); 23 *dronas* in Avanti (probably Malwa); and an immense quantity in *aparantanam* (western countries, the countries of Konkan); the borders of Himalayas and the countries where water-channels are made use of in agriculture”. Kautilya’s method of classification of rainfall areas in relation to the annual average quantity is indeed remarkable and he is the only classical author who treats this aspect in a nutshell covering almost the whole of the Indian subcontinent (Srinivasan, 1975). From this, it is evident that the spirit of the methodology of the measurement of rainfall given by Kautilya is the same as we have today, the only difference is that he expresses it in weight measures (Arth. Chapt. XXIV, Book II, P.130) while we use linear measure nowadays. Discussing the further geographical details of rainfall, he observes “when one-third of the requisite quantity of the rainfalls, both during the

commencement and closing months of the rainy season, and two third in the middle, then the rainfall is considered very even (सुषुमारूपम्).

As can be easily expected out of the agricultural necessity, the science of forecasting the rains had also come into existence and must have been developing empirically. It is further mentioned in the book Arthshastra that “A forecast of such rainfall can be made by observing the position, motion and pregnancy (garbhadhan) of Jupiter, the rising, setting and motion of Venus, and the natural or unnatural aspects of the Sun. From the movement of Venus, rainfall can be inferred”.

Discussing the classification of clouds and interrelationship of rainfall and agriculture, it is further added that “there are clouds which continuously rain for seven days; eighty are they that pour minute drops; and sixty are they that appear with the Sun shine”. When rain, free from wind and unmingled with sunshine falls, so as to render three turns of ploughing possible, then reaping of good harvest is certain.

The author of Astadhyayi, Panini (700 B.C.) refers to the rainy season as प्रावृष (IV, 3.26; VI, 3.14) and वर्षा (IV 3.18). The former was the first part of the season. These two parts were known as पूर्व वर्षा and अपरवर्षा (अवयवाद्व्युत्पत्तोः VII 3.11). He also refers to वर्षप्रमाण (III, 4.32) as:

वर्ष प्रमाण अलोपश्चास्यान्यतरस्याम् ।। Astadhyayi, III, 4.32 ।।

Citing examples for measurement of rainfall Panini further writes गोष्पदं वृष्टो देवः (rain equivalent to depression created by hoof of cow), सीताग्रं वृष्टो देवः (rain equivalent to fill the furrow created by indigenous plough). It is evident that the गोष्पद was the measure of the lowest rainfall.

Like Kautilya, Kanad and other precursor authorities such as Varahamihira also describe the device of the father of the raingauge and tell us how to measure rainfall from it. In Verse 2 of chapter 23, he states that constructing a circular bowl (कुण्डकम्) measuring one cubit, one should tell the amount of rainfall, viz.

हस्तविशालं कुण्डकमाधिकत्याम्बुप्रमाणनिर्देशः ।

पञ्चाशत्पलमादकमनेन मिनुयाज्जलं पतितम् । Vr.S.23.2 ।।

For calculating rainfall he adopts weight measures of pala, drona and adhaka (4 आढ़क = 1 द्रोण = 200 पल, and 1 आढ़क = 7 lbs. nearly). For measurement, rain water received in the bowl during the actual falling should be measured. The distribution of the rainfall according to time is discussed in the verses 6,7,8 and 9. These verses of Vrhata Samhita specify the amount of rainfall in various lunar mansions as:

हस्ताप्यसौम्यचित्रापोष्णधनिष्ठासु षोडश द्रोणाः ।
शतभिषगैन्द्रस्वातिषु चत्वारः कत्तकासु दशः ॥ Vr.S.23.6 ॥

श्रवणे मघानुराधाभरणीभूलेषु दश चतुर्युक्ताः ।
फल्गुन्या पञ्चकृतिः पुनर्वसो विशंतिद्रोणाः ॥ Vr.S.23.7 ॥

ऐन्द्राग्न्याख्ये वैश्वे च विशंति सार्षभे दश त्र्यधिका ।
आहिर्बुध्न्यार्यम्णप्राजापत्येषु पञ्चकृतिः ॥ Vr.S.23.8 ॥

पञ्चदशाजे पुष्ये च कीर्तिता वाजिभे दश द्वौ च ।
रौद्रेष्टादश कथिता द्रोणा निरूपद्रावेष्टेते ॥ Vr.S.23.9 ॥

In chapter XXXV, he says that phenomenon of rainbow is the result of spectro analysis of Sun's rays through clouds in the atmosphere. (XXXV.1)

सूर्यस्य विविधवर्णाः पवनेन विघाट्टिताः कराः साग्रे ।
वियति धनुः संस्थाना ये दश्यन्ते तदिन्द्रधनुः ॥ Vr.S.35.2 ॥

Parasara knew the contrivance of primitive raingauge and method of measuring the quantity of rain received (Vrhata Samhita, Chapt. 21, Garbhakhsnadhyaya). viz.

आढ़काज्श्चतुरो द्रोणानयां विघात् प्रमाणतः ।
धनुः प्रमाणं मेदिन्यां विघाद द्रोणाभिवर्षणम् ॥

चतुर्विंशद् गुलानाहे द्विचतुष्काड गुलोच्छिते ।
भाण्डे वर्षाम्बुसंपूर्णे, ज्ञेयमाढ़कवर्षणम् ॥ Vr.S.between 21.32 and 21.33 ॥

Epilogue:

From the various discussions presented in this chapter, we note that the knowledge related to cloud formation, precipitation and its measurement was of outstanding order in ancient India.

Condensation of evaporated water which is facilitated by the presence of dust particles etc. (which acts as nuclei as per modern meteorology), effect of yajna (यज्ञ), forests, reservoirs etc. on the causation of rainfall and the classification of clouds alongwith their colour, rainfall capacity etc. are thoroughly described in ancient Indian literature like Vedas, Puranas, Vaisesika Sutra, Astadhyayi, Arthasastra and Puranas. The forecasting of rainfall on the basis of natural phenomena like colour of sky, clouds, lightening, rainbow etc. was noteworthy. The instruments for measuring rainfall were developed and the principles were same as that of modern hydrology except that weight measure of Drona, Pala etc. were used instead of modern linear measurement.

The Indus civilization was able to find the seasonal variations in rainfall and methods to check the Indus floods. During the Mauryan period, it was possible to describe the distribution of rainfall in different areas of India and they are credited with the installation of first observatory worldwide. Modern meteorological facts like arid region of Tibetan rain shadow area and no rainfall due to polar winds are fully advocated in Puranas. The Jain and Buddhist works guessed the actual height of clouds. Knowledge of monsoon winds and their effects as conceived by ancient Indians is in accordance to modern hydro-science. These facts show that there was enriched knowledge of water science and associated processes, including meteorology during ancient times in India, which is at par to the modern water science.

INTERCEPTION, INFILTRATION AND EVAPOTRANSPIRATION

In the hydrological cycle, water which falls as rain reappears as infiltrated water, runoff, surface and underground water storage. This is also called as rainfall partitioning in modern hydrologic literature. The surface and ground water reservoirs are constantly getting replenished by recharge (precipitation) and depleted by evapotranspiration. The concepts related to the various components of rainfall partitioning were well conceived by the ancient Indians. This chapter briefly discusses about the ancient knowledge in this field as available in the Vedas and other ancient Indian literature.

Interception and Infiltration

Interception is the part of the rainfall that is intercepted by the earth's surface and which subsequently evaporates. Interception can amount to 15-50% of precipitation, which is a significant part of the water budget. One can distinguish many types of interception, which can also interplay with each other (Geritts, 2010). The term infiltration is used to describe the process involved where water soaks into or is absorbed by the soil (Horton, 1933) and it is one of the important components of the hydrologic cycle. In the hydrologic cycle, water from the oceans and various surface bodies on the land evaporates and becomes part of the atmosphere. The evaporated moisture is lifted and dispersed in the atmosphere until it precipitates on the land or in the ocean. The precipitated water may be intercepted and used in transpiration of the plants or may run over the ground.

Some references to interception are found intermixed with other topics in ancient Indian literature, such as explaining the effect of forests and vegetation on rainfall, cloud formation and environmental purification. Taithiriya Samhita mentions the effect of forests on causation of rainfall (TS. II, 4.9.3)

सौभययैवाहुत्या दिवो वृष्टिमव रुन्धे मघुषा सं यौत्यपां
वा एष ओषधीनां रसो यन्मध्वभदय एवौषधीभयो वर्षत्यथो
अद्भय एवौषधीभयो वृष्टिं नि नयति ।। TS,II,4.9.3 ।।

The verses 184.15-17 of Mahabharata state that the plants drink water through their roots. The mechanism of water uptake by plants is explained by the example of water rise through a pipe. It is said that the water uptake process is facilitated by the conjunction of air. This clearly reveals the knowledge of capillary action of soil in movement of water up and down as:

पादैः सलिलपानाच्च व्याधीनां वापि दर्शनात् ।
व्याधिप्रतिक्रियत्वाच्च विघटे रसनं द्रुमे ॥ MB.XII,184.15 ॥

वक्त्रेणोत्पलनालेन यथोद्ध्वं जलमाददेत् ।
तथा पवनसंयुक्तः पादैः पिवति पादपः । MB.XII,184.16 ॥

As far as infiltration is concerned, the scholar, Varahamihira clearly reveals it in the opening shloka of the Vrahat Samhita. Verse 1 tells us that at some places water table is higher and at others it is lower as:

पुंसां यथादेन शिरास्तथैव क्षितावपि प्रोन्नतनिम्नसंस्थाः (Vr.S,54.1)

It implies that the water veins beneath the earth are like veins in the human body, some higher and some lower. Verse 2 reads like this.

एकेन वर्णेन रसेन चाम्भश्च्युतं नभस्तो वसुधाविशेषात् ।
ननारसत्वं बहुवर्णतां च गतं परीक्ष्यं क्षितितुल्यमेव ॥ Vr.S.,54.2 ॥

It says that the water falling from sky assumes various colours and tastes from differences in the nature of earth. Thus, it implies that the infiltration of rainwater is the source of groundwater. The ground water is a complex function of rainwater. Rainwater originally has the same colour etc., but assumes different colours and tastes, after coming down to the surface of the earth and after percolation.

Three verses quoted by Bapudeva Sastri (in Sindhanta Siromani by Bhaskaracharya, Part II, Goladhayaya, Tripathi, 1969) belonging to an era prior to 1200 A.D., provide scientific details of the phenomena of fog or mist (for which the term रजः संहति has been used). The verses purport to say that at the end of rainy season dissipated clouds (moisture) hang near the surface of the earth and eclipse mountains, trees, vegetation cover or gardens and disappear through the activity

of air and heat from these surfaces. This clearly reveals the fact of interception by earthy materials, vegetation etc. and its disappearance with time by the activity of air and heat.

Evapotranspiration

The phenomena of evaporation and evapotranspiration and its interrelation with other hydrological processes were well understood by ancient Indians as evidenced by Vedic and other ancient literature. In Rig Veda (I, 6.10) it is mentioned that the sun ray breaks the water contained in the earth and other materials into minute particles, then these minute particles ascend by air and form clouds as:

इतो वा सातिमीमर्हे दिवो वा पार्थिवादधि ।
इन्द्र महोवार जसः ॥ R.V. I,6.10 ॥

नव्यं तदुक्थ्यं हितं देवासः सुप्रवाचनम् ।
ऋतमर्षन्ति सिन्धवः सत्यं तातान सूर्यो वित्तं मे अस्य रोदसी ॥ R.V.I,105.12 ॥

The verse I,105.12 of Rig Veda says that the water from the sea etc., evaporates due to the heat of Sun rays, which is the primary cause of rain formation. The same fact is revealed in the verse IV, 58.1 of Rig Veda as:

समुद्रादूर्मिर्मधुमां उदारदुपांशुना समृतत्वमानट् ।
घृतस्य नाम गुह्यं यदस्ति जिह्वा देवनाममृतस्य नाभिः ॥ R.V.IV,58.1 ॥

The verse VIII, 72.4 of the Rig Veda says that the atmospheric air gets heated due to Sun, then this heat reaches the Earth and converts the humidity into vapour and collects it as clouds, which is the cause of the rain and food production as:

जाम्यतीतये धनुर्वयोधा अरुहद्वनम् ।
धर्दे जिह्वायवधात् ॥ R.V.VIII,72.4 ॥

Like Rig Veda, the Yajur Veda also contains some knowledge about evaporation along with transpiration as:

देवो वनस्पतिर्देवमिन्द्रं वयाधसं देवो देवमवर्धयत् ॥ Y.V.,28.43 ॥
देवो देवैर्वनस्पति हिरण्ययर्णो मधुशाखः सुपिप्पलौ देवमिन्द्रमवर्धयत् ॥ Y.V.,28.20 ॥

It says that the vegetation attracts water from Earth and evaporates it to the atmosphere due to heat, wind etc. to form clouds. Similarly, Atharva Veda (IV, 25.2 and IV, 27.14) says that due to universal Sun and air, the water goes to the sky and comes back as rain. The evapotranspiration is caused due to Sun rays and wind as:

ययोः संख्याता वरिमा पार्थिवानि याभयां रजो युपितयन्तरिक्षे ।

ययोः प्रायं नान्वानशे कश्चन तौ नो मुञ्चन्तमंहसः ॥ A.V. IV.25.2 ॥

अपः समुद्राद दिवमुदवंहन्ति दिवस्पृथिवीमभि ये सृजन्ति ।

ये अभिदरीशानां मरुतश्चरन्ति ते नो मुञ्चन्तमंहसः ॥ A.V. IV,27.74 ॥

The verse I, 173.6 of the Rig Veda states that the atmosphere encompasses the Earth.

प्र यदित्था महिना नृभयो अस्त्यरं रोदसी कक्ष्ये नास्मै ।

सं विव्य इन्द्रो वृजनं न भूमा भर्ति स्वधावां ओपशमिव घाम् ॥ R.V. I,173.6 ॥

The solar phenomena are associated with the vault of the sky or heaven, while lightning. Rain and wind are referred to as occurring in the atmosphere (R.V., IV, 53.5, III., 56, I., 108.9-10) but it is doubtful whether the Rig Veda knew or guessed exactly the limit or the vertical height of the atmosphere, from these verses:

यदिन्द्राग्नी परभस्यां पृथिव्यां मध्यमस्यामवमस्यामुत स्थः ।

अतः परि वृषणावा हि यातमथा सोमस्य पिवतं सुतस्य ॥ R.V. I,108.9-10 ॥

षड् भारों एको अचरन्विभर्त्यृतं पर्षिष्टमुप गाव आगुः ।

तिस्त्रो महीस्परास्तस्थुरत्यागुहा द्वे निहिते दश्येका ॥ R.V. III, 56.2 ॥

त्री षधस्था सिन्धवास्त्रिः कवीनामुत त्रिमाताविदयेषु सम्राट् ।

ऋतावरीर्योषणास्तिस्त्रो अप्यास्त्रिरा दिवो विदये प्रत्यमानाः ॥ R.V.,III,56.5 ॥

त्रिख्तरिक्षं सविता महित्वना त्री रंजासि परिभूस्त्रीणि रोचना ।

तिस्त्रो दिवः पृथिवीस्तिस्त्र इन्वति त्रिभिर्ब्रतैरभि नो रक्षति त्मना । R.V.,IV,53.5 ॥

We read “Savitr (the Sun) encompassing them by magnitude pervades the three divisions of the firmament, the three world, the three brilliant spheres, the three heavens, the three-fold Earth. In

this connection a very significant question comes in to mind whether the three divisions of firmament denote troposphere, stratosphere, and ionosphere? Again in the triple divisions of the earth are we entitled to identify frigid, temperate and torrid zones, for different schools regarding Aryan home do recognize the Rig Vedic Aryans' knowledge about frigid and temperate zones and, it is just possible that in course of their ocean voyages and advances for habitat, they might have known torrid zone also.

The Vedic people were well aware that plants (or forests) had some influence on the loss of water and causation of rainfall (TS., II,4.9.3).

सौभययैवाहुत्या दिवो वृष्टमव रुन्धे मघुषा सं यौत्यापां वा एष ओषधीनां
रसो यन्मध्वभदय एवौषधीभयो वर्षत्यथो उद्भय एवौषधीभयो वृष्टिं नि नयति ॥ TS.,II,4.9.3 ॥

The concept and role of insolation is also referred to in the Taithiriya Samhita. Agni (Insolation) causes the rain to arise (T.S., II,4.10.2) as:

अहोरात्राभयां पर्जन्यं वर्षयतो ग्नेये धामच्छदे पुरोडाशमष्टाकपालं निर्वयेन्मारुतं
सप्तकपालसौर्यमेककपालमग्निर्वा इतो वृष्ट मुदीरयति मरुतः सृष्टां नयन्ति यदा खलु
वा असावादित्यो न्यङ्. रष्मिभिः प्यावर्ततेथ वर्षति धामछदिवि खलु वै भूत्वा
वर्षत्येता वै देवता वृष्ट्या ईशते ता एवं स्वेन भागधेयेनोप धावति ता ॥ TS.II,4.10.2 ॥

The epic Ramayana also furnishes a lot of information regarding the atmosphere, its conditions and cosmic regions, up to the distance of the Moon from the Earth. Entire atmospheric cosmic stretch was divided into nine regions, where last one is the longest. Ramayana (I.47.4) describes mythically the origin of the atmospheric regions.

वातस्कन्धा इमे सप्त चरन्तु दिवि पुचक ।
मारुता इति विख्याता दिव्यरुपा मामात्मजाः ॥ Ramayana.I,47.4 ॥

Intensive insolation and high temperature work as an agency of destruction or dispersion of the existing clouds is spoken of in VI.43.29 of Ramayana as:

निर्विभेद शरैस्तीक्ष्णैः करैर्मघमिवांशुमान् ॥ Ramayana.VI,43-29 ॥

In the Ramayana, we read about evaporation by the Sun's rays in general verse (II.105.20), and about the formation of clouds due to solar heating of the ocean (VII,32.68) as:

आयूर्षि क्षपयन्त्याशु ग्रीष्मे जलिमवांशवः ॥ Ramayana,II,105.20 ॥

उद्भूत आतपापाये प्योदानामिवाम्बुधौ ॥ Ramayana,VII,32.68 ॥

The insolational heating of the ocean water is also referred to in the Verse VII.25.30 of Ramayana.

दौदात्म्येनात्मनोद्वतस्ताप्ताम्भा इव सागरः ।

ततो ब्रवीद दशग्रीवः कुद्रः संरक्तलोचनः ॥ Ramayana.VII,25.30 ॥

In the twelfth skanda of epic Mahabharata, the atmosphere is divided into seven regions (Skanda, Spheres) and they are discussed in considerable detail. The wind named as आवह (M.B.XII, 328.37), blows with a loud noise. Another wind which drinks up water from the four ocean and having sucked it up gives it to the clouds in the sky and subsequently to rain god is called उद्धह (MB. XII, 328.38-39) as:

अम्बरे स्नेहमभयेत्य विधुदा भयश्च महाधुतिः ।

आवहो नाम संवाति द्वितीयः श्वसनो नदन ॥ MB.XII,328.37 ॥

उदयं ज्योतिषां शश्वत सोमादीनां करोति यः ।

अन्तर्देहेषु चोदानां यं वदन्ति मनीषिणः ॥ MB.XII,328.38 ॥

यश्चतुर्म्यं समुद्रेभ्यो वायुर्धारयते जलम् ।

उद्धत्याददते चापो जीभूतेभ्योम्बरे निलः ॥ MB.XII,328.39 ॥

Apart from the wind, the sun was realized as the main cause of evapotranspiration. The Vana Parva tells us that the Sun evaporates moisture from all plants and water bodies and causes rainfall (MB.III.3.49). The epic informs us of various types of clouds and atmospheric layers as well.

त्वमादायांशुमिस्तेजो निदार्घो सर्वदेहिनाम् ।

सवौषाधिरसानां च पुनर्वर्षासु मुञ्चसि ॥ MB.III.3.49 ॥

संदहत्यैकार्णवं सर्वं त्वं शोषयसि रश्मिभिः ॥ MB.III.3.59 ॥

Kanada in his Vaisesika Sutra (Vais. Sutra., 5.2.5) explains the cause of evaporation of water thus, “the Sun’s rays cause the ascent of water, through conjunction with air”:

नाइयो वायु संयोगादारोहणम् ॥ Vais.Sutr.5.2.5 ॥

Kanada was also acquainted with convection currents in the atmosphere which he refers to in very scientific terms as:

नोदनापीडनात्संयुक्त संयोगाच्च ॥ Vais.Sutr.5.2.6 ॥

Author and commentator Sankara Misra (1600 AD) has beautifully explained this and illustrated it with the example of a kettle of water heated from below (Tripathi, 1969). It conclusively proves that the great philosopher Kanada knew that the Earth is heated by sun’s rays through radiation and convection currents in the atmosphere.

Various Puranas inform us that there are seven regions or layers (वातस्कन्ध) in the atmosphere or there are seven types of winds (Vayu. 49.163). Narada Purana speaks of seven air channels (60.13) viz. सप्तैतेवायुमार्गाः, Kurma Chapt. 41.6-7 also reveals same thing with little variations as described here:

रसातलतलात्सप्त सप्तैवाध्वतलाः क्षितौ ।

सप्त स्कन्धास्तथा वायोः सप्तह्रमसदना द्विजाः ॥ Vayu.49.163 ॥

आवहः प्रवहश्चैत ततैवानुवहः पुनः ।

सम्बहो विवहश्चैव तदूर्ध्व स्यात्परावहः ॥ Kurma.41.6 ॥

तथा परिवहश्चैव वायोर्वे सप्त नेमयः ॥ Kurma. 41.7 ॥

The phenomena of evaporation, cloud formation and their relationship with winds or regions of atmosphere (वातस्कन्ध) are quite satisfactorily described in several Puranas (Brahamand Vol. II, Chapt. 9., Vayu. Chapt. 51, Linga, I,41, Matsya, I,54) and a full-fledged separate chapter has been devoted to them in these topics, which positively evinces that due importance of this branch of meteorology was realized. Some of the verses are quoted here as:

नावष्टया परिविश्वेत वारिणा दीप्यते रविः ।
तस्मादयः पिबन्त्यो वै दीप्यते रविरंबरे ॥ Brahmand, Vol.II,9.138 ॥

तस्य ते रश्मयः सप्त पिबंत्यंभो महार्णवात् ।
तेनाहारेण संदीप्ताः सूर्याः सप्त भवंत्युत ॥ Brahmand, Vol.II,9.139 ॥

वर्षाघर्मो हिमं रात्रिः संध्या चैव दिनं तथा ।
शुभाशुभं प्रजानां च ध्रुवात्सर्वं प्रवर्तते ॥ Vayu. 51.11 ॥

ध्रुवेणाधिकृतांश्चैव सूर्योपावृत्य तिष्ठतिः ।
तदेषदीप्त किरणः स कालीग्निर्दिवाकरः ॥ Vayu. 51.12 ॥

सूर्यः किरणजालेन वायुमुक्तेन सर्वशः ।
जगतो जलमादत्ते कृत्स्नस्य द्विज सत्तमाः ॥ Vayu. 51.13 ॥

Above lines of Vayu Purana explain that the sun rays along with the air, extract water from earth. The Linga Purana (I,41.11,21 and 30), specifically recognizes the roll of sun rays in evaporation of water, which gets converted to clouds and subsequent rainfall.

वैष्णुतो जाठरः सौरावारिगर्भास्त्रयोनियः ॥ Linga. I,41.11 ॥

याश्चासौ तपने सूर्यः पिवन्नभो गभस्थिभिः ।
पार्थिवाग्निविभिश्चसौ दित्यः शुचिरिति स्मृत ॥ Linga. I,41.11 ॥

वसंते चैव ग्रीष्मे च शनैः स तपते त्रिभिः ।
वर्षास्वथो शरदि च चतुर्भिस्स्यं प्रवर्षति ॥ Linga. I,41.30 ॥

ध्रुवेणाधिष्टताश्चापः सूर्यो वै गुह्य तिष्ठति ।
सर्वभूतशरीरेषु त्वापो हयानुश्चताश्चियाः ॥ Matsya. I,54.29 ॥

तेजोभिः सर्वलोकेभ्य आदत्ते रश्मिभिर्जलम् ॥ Matsya. I,54.31 ॥

समुद्राद्वायुसंयोगात् वहन्त्यापो गभस्तयः ।
ततस्त्वृतुवशात्कालेपरिवर्तनं दिवाकरः ॥ Matsya. I, 54.321 ॥

The celebrated Jain treatise ‘Surya Prajnapti’ has dwelt upon at length on insolation, radiation and reflection of the sun’s light and energy and heating of the earth and various surfaces. Its conception of a contribution to “albedo” appears to be something wonderful, when we take into account the fact that the work was composed at least nearly half a millennium B.C. The concept of albedo is an important aspect of modern hydro-meteorology. The evapotranspiration process is greatly affected by the albedo.

In Prabhrta 4, Sutra 25, detailed discussions are there dealing with insolation or heat of the Sun (तापक्षेत्र), Prabhrta 5, Sutra 26 (designated as लेखा प्रतिहति, reflection of sun’s light), presents a detailed discussion on the phenomena of scattering of sun’s light, radiation, insolation, reflection and albedo and gives accurate scientific details. First, it mentions twenty theories on reflection of the sun’s light held by the adherents of other sects (परतीर्थिकानाम्). Then, it refers to another important fact that unseen (invisible) objects also possess reflective capacity.

In aphorism, 30 of the 9 Prabhrta, discusses about the nature of convection and radiation heating through the sun’s ray with reference to earth surface, water bodies and its objects and atmosphere and its continents. The author of the Surya Prajanapti also speaks that slanting rays of the sun give lesser heat and vertical ones greater heat. This is discussed with reference to the rising of the sun, noon and evening and different places (or latitudes). This shows that during Jain period, the Indians were well known about the heat exchange processes with in-depth technical theories.

Epilogue

The various references and discussions presented in the chapter show the ancient Indians had developed significant understanding about the processes of interception, and infiltration. The interception of water by vegetation and hanging of water particles near the surface of Earth on other materials was also observed, which disappear through the activities of wind and heat. The modern soil science tells us that the soil is composed of interconnected pore spaces. This was clearly realized by the ancient Indians and was compared with the veins in the human body, through which infiltration takes place, which is the source of ground water. Ancient Indians also developed a very scientific knowledge about evaporation and transpiration. That sun rays, wind, humidity, vegetation etc. are the major causes of evapotranspiration, was known to them. The ancient Indians had realized the importance of evapotranspiration as an important facet of water cycle, energy circulation and food production and, for maintaining the natural eco-system. Solar phenomena, lightening, wind, cloud formation etc. take place in lower layer of the atmosphere.

Atmosphere was divided in troposphere, stratosphere and ionosphere and globe in torrid, temperate and frigid zones which is comparable to modern meteorology. Plants drink up water through roots which is facilitated by the conjunction of air is alluded to in Mahabharata which fully corroborates the modern concept of capillarity in soil, water and plant relationship. The fact that plants and forests have some influence on water loss, differential rate of heating of the continents and water bodies, formation of convection currents and their effects were well understood. However, it is point of further research in the ancient hydrologic literature whether there were specific instruments/techniques to quantify the processes of interception, infiltration and evapo-transpiration?

GEOMORPHOLOGY AND SURFACE WATER

Rivers are invaluable not only for humans but to all forms of life. Not only are rivers a great place for people, but people use river water for drinking-water supplies and irrigation, to produce electricity, to transport merchandise and to obtain food. Rivers are major aquatic landscapes for all manners of plants and animals. Rivers even help keep the aquifers underground full of water by discharging water downward through their stream beds.

The knowledge about stream flow is an essential requirement for construction of hydraulic structures such as dams. The first major human settlements in the Indus Valley (3000-1500 B.C.); called Indus civilization or Harappan civilization, demonstrated a high degree of hydraulic engineering skills (Pandey, 2016). After the Harappan culture came to its abrupt end, the Vedic age was started. According to the Vedic knowledge, all life on this planet evolved from Apah (water). Literary references and archaeological data from about 6th century BC onwards indicate the development of embankments, canals and other hydraulic works. Literature suggests that there were a large number of hydraulic structures built (dams, canals and lakes) during the Mauryan period in Indo-Gangetic plains and other parts of the country for irrigation and drinking purposes (Shaw et al., 2007; Sutcliffe et al., 2011). Surprisingly, many of these structures were equipped with the spillways to consider the flood protection measures. This chapter briefly discusses about the ancient knowledge in the field of geo-morphology and surface water hydrology as available in the Vedas and other ancient literature.

The Rig Vedic hymns X.B2.1 and X.121.1 state that the creation had started with the origin of water and the cosmic golden egg (embryo) (हिरण्यगर्भ) which very well fits in the geological and biological evolution of the earth with the water age, origin of zoophytes, primeval fishes, reptiles, invertebrates, vertebrates and mammals.

चक्षुषः पिता मनसा हि धीरो घृतमेने अजनन्मन्माने ।

यदेदन्ता अददृहन्त पूर्व आदिदद्यावापथिवी अप्रथेताम् ॥ R.V.X, 82.1 ॥

हिरण्यगर्भः समवर्तताग्रे भूतस्य जातः पतिरर्क आसीत् ।

स दाधार पृथिवी घामुतेमां कस्मे देवाय हविषा विधेम् ॥ R.V.X, 121.1 ॥

According to the Rig Veda, the earth abounds in heights, bears the burden of mountains and supports the trees of the forests in the ground (क्षमा). She quickens for she scatters rain, and the showers of heaven are shed from the lightning of its clouds. The Earth is great (मही), firm (दृढ) and shining (अर्जुनी).

Perhaps the Rig Vedic Aryans had the concept of knowing slopes also of a region with the help of rivers as indicated (R.V.IX, 88.6) below:

एते सोमा अति वाराण्यव्या दिव्या न कोशासो अभ्रवर्षाः ।
वृथा समुद्रं सिन्धवो न नीचीः सुतासो अभि कलशां असृग्रन ॥ R.V.IV, 88.6 ॥

Talking about the river flow whose turbulence is lost after meeting the oceans, the Rig Veda says:

समन्या यन्त्युय यन्त्यन्याः समानमूर्व नद्यः पृणान्त ॥ R.V.II, 35.3 ॥

In the verses IV,18.6 and IV,19.3 of the Rig Veda, it is said that the rivers are the daughters of sun and cloud. They run towards oceans breaking the soil, rocks etc. coming on their way. They flow in through zig-zap paths:

एता अर्षन्त्यलालाभवन्तीऋतावरीरिव संक्रोशमानाः ।
एता वि पुच्छ किमिदं भतन्ति कमापो अद्रिपिरिधिं रुजान्ति ॥ R.V.IV, 18.6 ॥

During the Rig Veda period, Aryans were probably acquainted with the river velocity at different stages. One verse (VI 24.6) mentions the high speed of mountainous rivers flowing down the slope as:

वि त्वदापौ पर्वतस्य पृष्ठादुक्थेभिरिन्द्रानयन्त यज्ञैः ॥ R.V.VI, 24.6 ॥

By the time of Sam Veda, Yajur Veda and Atharv Veda, the Indians had come to acquire sufficient knowledge of physiography and geomorphology. This is established by the geographical technical terms – उपह्वर (mountain slopes, SV.II, 5.9), इरिण (cleft or ऊपर), शिला (stony place), क्षयण (habitable place), काट (forest having a difficult communication), हृद् (lake), लोप (rugged lands or bad lands) (TS,IV,5.9.1). In the Sam Veda, we come across a brief but fine

description of a river mouth and a wave of the sea opposite to the mouth of a river sends into it a portion of its water (SV XIV, 4). The prithvi sukta (XII) of the Atharv Veda, furnishes a concise account of physiography – mountains, snowcapped mountains, forest lands, plain areas (सम) and perennial stream or slopes (प्रवत्). Following hymn of Atharv Veda illustrates that if the water source is on mountains, then the river formed will be perennial and will flow with high speed (AV.I.,15.3) as:

ये नदीनां संस्त्रवन्त्युत्सासः । A.V.I.,15.3 ॥

Similarly, verse II, 3.1 of the Atharv Veda reveals the same fact saying that the rivers originating from snowclad mountains will keep on flowing in summer also.

अदो यदवधावत्यवत्कमाधि पर्वतात् ॥ A.V.II,3.1 ॥

In the Gopatha Brahmana, the nomenclature for a meandering river is विपाट (II.8). It was also acquainted with two types of springs or falls, namely hot and cold (शीतोष्णाविहोत्सौ G.B.II,8). The celebrated epic Ramayana also reveals very rich and accurate knowledge of various types of geomorphological patterns. Some of the geomorphological patterns as mentioned in the Ramayana related to water are rivers and rills and plateaus, caverns and fountains (II,54.42.) the plain tracts (II,56.11), sandy banks of rivers (Rama. II,55.31):

सरित्प्रस्त्रवणस्थान् दरीकन्दरनिर्झरान् ॥ Rama. II, 54.42 ॥

समभूमितले रम्ये द्रुमैर्बहुभिरावृते । पुण्ये रंस्यामहे तात चित्रकूटस्य कानने ॥ Rama.II.56.11 ॥

विचित्रवालुकजलां हंससारसनादिनाम् ।

रेमेजनकराजस्य सुता प्रेक्ष्य तदा नदीम् ॥ Rama. II,55.31 ॥

Those lands watered by the Ganga have been described as dense and hard to track (Rama. II,85.4) as:

कतरेण गमिष्यामि भरद्वाजाश्रमं यथा ।

गहानोयं भृशं देशो गङ्गानूपो दुरत्ययः ॥ Rama. II,85.4 ॥

Knowledge of water falls (II,94.13) and descent of a river (II,103.25) is described as below:

जलप्रपातैरुदभेदैर्निष्पन्दैश्च क्वचित् ।

स्त्रवदिभर्भत्ययं शैलः स्त्रवन्मद इव द्विपः ॥ Rama. II,94.13 ॥

नर्दी मन्दाकिनी रम्यां सदा पुष्पितकाननाम् ॥ Rama. II,103.24 ॥

शीघ्र स्त्रोतसमासाघ तीर्थ शिवमकर्दमम् ।

सिषिचुस्तूदकं राजे तत एतद् भवत्विति ॥ Rama.II,103.25 ॥

How after melting of snow, a mountainous topography becomes charming is spoken of thus – हिमात्यये नगमिव चारुकन्दरम् (Ramayana II, 7.15). The author of the epic has also marked “river erosion on non-resistant or soft steep river bank (II,63.46; V,34.19; VII,14.18) as:

रुणद्धि मृदु सोत्सेधं तीरमम्बुरयो यथा ॥ Rama.II,63.46 ॥

चित्तं हरसि मे सौम्य नदीकूलं यथा रयः ॥ Rama.,V,34.19 ॥

सीदन्ति च तदा यक्षाः कूला इव जलेन ह ॥ Rama.,VII,14.18 ॥

In the verse VII, 23.42 of the Ramayana, we read about the erosive action of the downpour of rain on mountains. viz.

सायकैश्चापवकभ्रष्टैर्वज्रकल्पैः सुदारुणैः ।

दारयन्ति स्म संकुद्वामेघा इव महागिरिम् ॥ Rama., VII, 23.42 ॥

The Mahabharata divides the Himalayan mountains into three regions. It mentions large tracts of desert several times (I, 70.2). In certain context the word नदीकच्छ is used. Most probably it indicates the land form which now-a-days is called delta.

एक एवोत्तमवलः क्षुत्पिपासाश्रमान्वितः ।

स वनस्यान्तमासाघ महच्छून्यं समासदत् ॥ M.B.,I,70.2 ॥

नदीकच्छोद्भवं कान्तमुच्छतध्वजं संनिभम् ॥ M.B.,I,70.17 ॥

In Panini’s Astadhyayi (600-700 BC), we come across several important geomorphological patterns. The grammarian calls a river moving and breaking its banks as भिन्ध and that whose water overflows the banks as उद्ध्य (III,1.15). Glacier is named हिमानी (IV,1.49) as:

इन्द्रवरुणभवशर्वरुद्रमृडहिमारण्ययवयवनमातुलाचार्यणमानुक ॥ Astadhya.,IV,1.49 ॥

Topography and geomorphology have been discussed very well in the Arthasastra by Kautilya (4th century BC) during the Mauryan period. Various types of lands such as “forests, villages, waterfalls, level plains and uneven ground”, stretching between the Himalayas and ocean (Arthasastra, Trans. by Shamshastri P.404) have been mentioned there. At various places he speaks of fertile, infertile, cultivable, uncultivable and waste land, which reveals that he must have possessed good knowledge of the science of soil also at that time.

The Vayu Purana refers to various types of topography namely lakes, dales, barren tracks (Chapter 38), rocky through between mountains (अन्तद्रोणी) (38.36).

पश्चिमायां दिशि तथा येन्तद्रोणिविस्तराः ।
तान्वर्ण्यमानास्तत्वेन शृणुतेमान्द्विजोत्तमाः ॥ Vayu.,38.36 ॥

The chapter 38 of Vayu Purana also speaks about the large number of hot springs in a mountainous region (38.78).

तथा हयनलतप्तानि सरांसि द्विजसत्तमाः ।
शैलकुक्ष्यन्तरस्थानि सहस्राणि शतानि च ॥ Vayu.,38.78 ॥

In the Markandeya Purana (53.21-22), we come across a peculiar type of topography found “in the Kimpurusaversa and seven other countries” where water bubbles up from the ground as:

नवस्वपि च वर्षेषु सप्त सप्तकुलाचलाः ।
एकेकस्त्रिस्तथा देशे नघश्चाद्रि विनिः सृताः ॥ Markandeya P.53.21 ॥

यानि किं पुरुषाघानि वर्षाण्यष्टौ द्विजोत्तमः ।
तेषूद्भिज्जानि तोयानि नैवं वार्यत्र भारते ॥ Markandeya P.53.22 ॥

The Vishnu Purana (II,5.3) classifies the soils of sub-terranean region in seven categories viz. (1) black, (2) white or yellowish, (3) blue or red, (4) yellow, (5) gravelly, (6) hilly or boulder and (7) golden hued, as:

शुक्लकृष्णाः पीताः शर्कराः शैलकाज्वनाः ।

The Vrhatsamasa (6-7 century AD) (Tripathi, 1969) has many scientific and mathematical enumerations conforming to some hydrographical or hydrological laws. Anguttaranikaya (before 400 B.C.) classifies lakes into four categories (part II, page 105, Tripathi, 1969).

Epilogue

From the above discussions, we see that in ancient India, the knowledge of streamflow and geomorphology was well developed on scientific lines. A number of hydraulic structures were constructed during that time for irrigation and domestic purposes. The techniques of knowing slope of an area by means of a flowing river and dimensions of river at various stages along with velocity were developed. That the mountainous rivers are generally perennial and deposition of fertile soil takes place periodically on flood plains was understood which is in accordance to the modern experiences. The arrangement of sluice gates was also made in the dams for flood protection purposes. Various types of topographies such as springs, water falls, mountainous, plateau, eroded land etc. along with many geographical terms such as शिला, इरिण, क्षयण, लोप were used. Land classification such as fertile, infertile, cultivable, waste land etc. and soil classifications, such as black, yellow, red, gravelly, boulders etc. was well in vogue before 4th century B.C. These are in vogue even at present and hence, can be regarded as the important achievement of the ancient Indians in this field.

Chapter-6

GROUND WATER

Groundwater development and utilization has been of great interest from ancient times in arid and semi arid regions of Asia where the activities of man were controlled by the occurrence of water. From the dawn of history until comparatively recent times the source of water of the springs and streams had constituted a puzzling problem and had been the subject of much speculation and controversy. Mohenjo-Daro was a major urban center of the Indus civilization during the early Bronze Age (around 2450 BC). Recently, Angelakis and Zheng (2015) found that the city was receiving water from at least 700 wells. The design of these wells was varying from circular to pipal leaf shaped (Khan, 2014). Figure 6.1 shows the wells constructed in about 2600 BC, discovered at Lothal, an important Harappan site.



Figure 6.1: Wells discovered at Lothal, 2600 BC
(Source: <https://rainwaterharvesting.files.wordpress.com>)

The ancient western science of groundwater, which generally assumed that the water discharged by the springs could not be derived from the rainfall, was based on their belief that: (i) the rainfall was inadequate in quantity and (ii) the earth was too impervious to permit penetration of the rainwater far below the surface. In contrast to above wild theories, the ancient Indian literature contains the very valuable and advanced scientific discourse on ground water.

In Rig Veda, Sam Veda and Yajur Veda we get concepts of hydrological cycle and water use through wells etc., which clearly imply the use of groundwater. In the area of groundwater renowned astronomer, astrologer and mathematician, Varahmihira (AD. 505-587), author of

Vrhat Samhita, which is esteemed for its learning of many important branches of knowledge, in the 54th chapter entitled ‘Dakargalam’, deals with ground water exploration and exploitation with various surface features, that are used as hydrologic indicators to locate sources of ground water, at depths varying from 2.29 m to as much as 171.45 m (Prasad, 1980). The hydrologic indicators, described in this ancient Sanskrit work, include various plant species, their morphologic and physiographic features, termite mounds, geophysical characteristics, soils and rocks. All these indicators are nothing but the conspicuous responses to biological and geological materials in a microenvironment, consequential to high relative humidity in a ground water ecosystem, developed in an arid or semi arid region. Variation in the height of water table with place, hot and cold springs, groundwater utilization by means of wells, well construction methods and equipment are fully described in the Dakargalam (Jain et al., 2007).

The treatise on Dakargalam (science of underground water) by Manu is referred to in the Vrhat Samhita. By the latest his time must be (400BC-200BC). Varahmihira alludes that मनुना विरचितं दकार्गलम which clearly indicates Manu’s contribution to this science. This also indicates that the science was cultivated in India several centuries before Christ and that it was developed by indigenous people altogether independently. Varahmihira has utilized to a greater extent another treatise on the science of underground water and water table, written by ‘Saraswat’. Rather the farmer (Manu) appears to give a preference to the latter over the Manava Dakargalam (Vrhat Samhita, 54.99).

सारस्वतेन मुनिना दकार्गलं यत् कृतं तलवलोक्य ।

आर्याभिः कृतमेतद्वृत्तैरपि मानवं वक्ष्ये ॥ Vr.S.54.99 ॥

As far as underground water and water table is concerned as a science, a brief survey of chapter 54 of the Vrhat Samhita designated as ‘Dakargalam’ is furnished below. Apart from the wider term ‘Dakargala’, there are two other technical terms शिरा and शिराविज्ञान used in this chapter (Verse 54.1, 54.61-62) viz.

धर्म्यं यशंस्यं च वदाम्यतोहं दकार्गलं येन जलोपलब्धिः ।

पुंसां यथाग्देषु शिरास्तथैव क्षितावपि प्रोन्नतनिम्न संस्था ॥ Vr.S.54.1 ॥

मरुदेशे भवति शिरा यथा तथातः परं प्रवक्ष्यामि ।

ग्रीव करभाणामिव भूतलसंस्थाः शिरा यान्ति ॥ Vr.S.54.62 ॥

The term शिरा implies arteries of water or streams and the शिराविज्ञान exactly conveys the meaning of water table. Verse 54.1 above tells us that at some places water table is higher and at others it is lower, resembling the veins in the human body. From Verse 54.2 we learn that water table is a complex function of rainwater.

एकेन वर्णेन रसेन चाम्भश्च्युतं नभस्तो वसुधाविशेषात् ।

ननारसत्वं बहुवर्णतां एवं परीक्ष्यं क्षितितुल्यमेव ॥ Vr.S.54.2 ॥

It means, the water which falls from the sky originally has the same colour and same taste, but assumes different colour and taste after coming down on the surface of the earth and after percolation. Figure 6.2 shows infiltration and percolation process for an unconfined aquifer leading to different zones of groundwater.

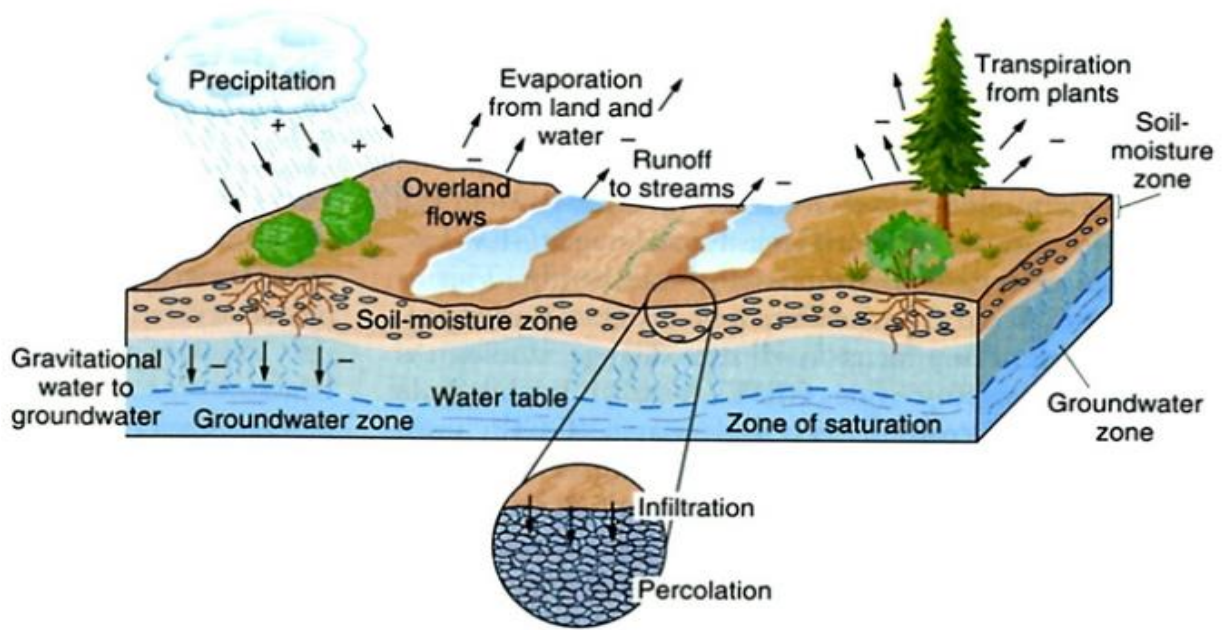


Figure 6.2: Unconfined aquifer showing different zones: uppermost soil moisture where precipitation infiltrates downward to the water table where all the open pore spaces are filled or saturated (Source: UNO, International programs)

In the later verses of Dakargalam, the modes of occurrence of sub-terrainian water and its depth at different places are given. Verse 54.3, 54.4 and 54.55 inform us that the sub-terrainian streams are rainfed in all the quarters and also apart from nine arteries, thousands more are present flowing to various directions as:

पुरुहूतानलयमनिऋतिवरुणपवनेन्दुशंकरा देवाः ।

विज्ञतव्याः क्रमशः प्राच्याघानां दिशां पतयः ॥ VR.S.54.3 ॥

दिक्पतिराज्ज्ञा च शिरा नवमी मध्ये महाशिशनाम्बी ।

एताभयोत्याः शतशो विनिः सृता नाममिः प्रथिताः ॥ Vr.S.54.4 ॥

पातालाटूर्ध्वाशिरा शुभा चतुर्दिक्षु संस्थितता याश्च ।

कोणदिगुत्था न शुभाः शिरानिमित्तान्यतो वक्ष्ये ॥ Vr.S.54.5 ॥

Rock or soil structure and depth of water table from the surface of the earth is described correctly in various verses. Verse 54.7 describes the various symptoms of occurrence of water along with pervious and impervious strata.

चिन्हमपि चार्धपुरुषे मण्डूकः पाण्डुरोऽश मृत पीता ।

पुटभेदकश्च तस्मिन् पाषाणो भवति तोयमधः ॥ Vr.S.54.7 ॥

Meaning: on digging we will get yellow frog at a depth of half purusha (1 purusha = height of man with erected hand = 7.5 feet) then yellow soil, then rock and then ample amount of water.

Similarly, many other verses describe some 70 odd field situations or ecological spectra from which it would be possible to deduce the presence of underground springs. Actually the technique of underground water exploration as described by Varahmihira depends upon a close observation of naturally occurring specific signs in the terrain, comprising the flora, fauna, rocks, soils and minerals, whose state and variation can be logically or empirically linked up with the presence of underground springs in the vicinity.

One startling factor emphasized in details by Varahmihira is the role of termite knolls as indicator of underground water. Apart from the underground water exploration, some of the verses of the chapter deal with topics such as digging of wells, their alignment with reference to the prevailing winds, dealing with hard refractory stony strata, sharpening and tempering of stone-breaking chisels and their heat treatment, treating with herbs of water with objectionable taste, smell, protection of banks with timbering and stoning and planting with trees, and such other related matters.

Some thirty-three verses of the Varahsanhita deal with termite, standing alone by themselves or associated with vegetation, thirty with vegetational factors alone and the remaining using other factors to help in exploration.

जम्बूवृक्षस्य प्राग्वल्मीको यदि भवेत् समीपस्थः ।

तस्माददक्षिपार्श्वे सलिलं पुरुषद्वये स्वादु ॥ Vr.S.54.9 ॥

उदगर्जुनस्य दृश्यो बल्मीको यदि ततोर्जुनाद्वस्तेः ।

त्रिभिरम्बु भवति पुरुषैस्त्रभिर्धसमन्वितैः पश्चात् ॥ Vr.S.54.12 ॥

Meaning: If there is a termite mound nearby to the east of a Jambu tree, plenty of sweet water, yielding for a longtime occurs at a depth of two purushas, at a distance of three hastas (cubit) to the south of the tree (54.9). Similarly, an Arjuna tree with a termite mound to the north shows water at a depth of 3.5 purushas at a distance of 3 hastas to the west.

The mound builder variety of the termites are responsible for the impressive soil structure called ‘Ant-hills’ in lay terms, but referred to as termite – knolls – mounds – spires, or – prominences by the scientists. These are familiar features of most tropical and subtropical landscape and are of interest to us in the technique of exploration of underground springs. Without exception, the water requirements of the insects are generally very high and they need to protect themselves against fatal desiccation by living and working within the climatically sealed environment of their nest or within earth-covered galleries. According to Rao et al. (1971) the atmosphere within the nest has to be maintained practically at saturation moisture level (99-100% relative humidity). It is a matter of common observation that whenever a termite nest or runway is damaged, the insects immediately rush to the breach and repair it with wet soil brought up from within the nest. From an overall consideration of the evidence it seems to be safe to conclude that, while normally the insects use every readily available near a source of water close to the ground surface, under conditions of severe climatic stress, they can and probably do descend to the water table, no matter how deep it may be. Hence, a well-developed, active, persistent colony of mould-building termites can be taken as an indication of underground springs in the proximity.

E.G.K. Rao (1979) observed the alignment of the termite knolls in the dry-jungle uplands of coastal Mysore as well as the Deccan Plateau area, and testified the verses of Vrhat Samhita

relating the same. Following verse of Vrhat Samhita suggests that the author was aware of this tendency of mould builders.

बल्मीकानां पक्कृत्यां यधेकोभयुच्छतः शिरा तदधः ॥ Vr.S.54.95 ॥

Meaning: If in a line of termite-moulds one is found to be raised up (taller), water vein is to be found within it.

Similarly, Verse 82 says that if a group of five termites are found in a place, and the middle one among them is found white, water should be declared in it at a depth of fifty five purushas (i.e. 7.5' X 55 = 412.5 feet).

It is a matter of common observation that many times territories are met with in close association with trees; and it is quite common sight to see termite mounds completely covered over with grass or vegetation. Very close observation is often necessary to detect the termitary. The ancient Indian scholar has exploited this association quite extensively in the exploration of underground springs as discussed below:

जम्बूस्त्रिवृता मौर्वी शिशुमारी सारिवा शिवा श्यामा ।
वीरुधयो वाराही ज्योतिष्मती गरुणवेगा च ॥ Vr.S.54.87 ॥

सूकरिकमाषपर्णीव्याघ्रपदाश्चेति यघहेर्निलये ।
बल्मीकादुत्तरतात्स्त्रीभिः करैस्त्रिपुरुषे तोयम ॥ Vr.S.54.88 ॥

Meaning: If Jambu, Trivrt, Maurva, Sisumari, Sariva, Siva, Syama, Varahi, Jyotismati, Garudavega, Sukarika, Masaparni, Vyaghra Pada trees and creepers are seen by a termite mound, there is water 3 hastas to its north at a depth of 3 purushas”.

The botanical names of the flora mentioned in the above verses are: Jambu (Eugenia Jambos, Engenia Jambolana), Trivrt (Ipomea turpethum), Maurvi (Sanservieraroxburgiana), Sisumari (?), Sariva (Hemidesmus indicus), Siva (Several Plants: Cucumis Utilissimus, Terminalia Chebula, Emblica officinalis, Cynodon dactylon), Syama (Ichnocarpus fructens – black creeper, Krsna Sariva, Datura metal, Agalala rox-burgiana, Panicum coloncum etc.), Sukarika (Lyccopodium imbricatum, I. Clovatum), Masaparni (Glycine debitis, G. Labialis).

Similarly, various other verses of the chapter 54 of Vraht Samhita are related to the underground water exploration with relation to combination of different symptoms, as below:

अतृणे सदृणा यस्मिन् सतृणे तृणवर्जिस्मिता महीयत्र ।
तस्मिन् शिरा प्रदिष्टा वक्तव्यं वा धनं वास्यिन ॥ Vr.S.54.52 ॥

Meaning: if in a grass less place, there is a patch of grass or in a grassy place, there is a grassless place, water or treasure is indicated.

कण्टक्यकण्टकानां व्यत्यासेम्भास्त्रिभिः करैः पश्चात् ।
खात्वा पुरुषत्रितयं त्रिभागयुक्तं धनं वा स्यात् ॥ Vr.S.54.53 ॥

Meaning: a flourishing thorny tree in the midst of non-thorny trees or vice-versa indicates water or treasure at a depth of 3 ¾ Purushas at a distance of 3 hastas to the west”.

यस्यामूष्मा धात्र्यां धूमो वा तत्र वारि नरयुगले ।
निर्देष्टव्या च शिरा महता तोयप्रवाहेण ॥ Vr.S.54.60 ॥

Meaning: where there is stream or smoke issuing from the ground, an abundant water vein will be struck at a depth of 2 Purushes. Varahamihira has also discussed the occurrence of underground water in the desert region. He further says that sub-terranean streams or water table in the desert region takes the shape of the neck of a camel and is at a great depth from the surface of the earth as:

मरुदेशे भवति शिरा यथा तथातः परं प्रवक्ष्यामि ।
ग्रीवा करभाणाभिव भूतलसंस्थाः शिरा यान्ति ॥ Vr.S.54.62 ॥

Geological strata scheme of the modern artesian well fully corroborates this.

In the Verse 102 of the Vraht Samhita , it is described how water occurs in a mountainous region.

विभीतको वा मदयान्तिका वा यत्रास्ति तस्मिन् पुरुषत्रयेमभः ।
स्यात्पर्वतस्योपरि पर्वतोन्त्यस्तत्रापि मूले पुरुषत्रयेम्भः ॥ Vr.S.54.102 ॥

सशर्करा ताम्रमही कषायं क्षारं धरित्री कपिला करोति ।

आपाण्डुरायां लवणं प्रदिष्टं मृष्टं पयो नीलवसुन्धरायाम् ॥ Vr.S.54.104 ॥

Above verse (54.104) explains the relation of soil and water. It says that pebbly and sandy soil of copper colour makes water astringent. Brown-coloured soil gives rise to alkaline water, yellowish soil makes water briny and in blue soil underground water becomes pure and fresh.

In Ramayana we come across the knowledge of artesian wells. The verses VI,22.37-38 say that the water from deep earth comes out by force continuously through the hole created by arrow of Lord Rama as:

निपातितः शरो यत्र वज्राशनिसमप्रभः ॥ Rama., VI,22.36 ॥

तस्माद व्रणमुखात् तोयमुत्पपात रसातलात् ॥ Rama., VI,22.37 ॥

स बभूत तदा कूपो व्रण इत्येव विश्रुतः ।

सततं चोत्थितं तोयं समुद्रस्येव दृश्यते ॥ Rama., VI,22.38 ॥

It clearly and very scientifically explains the artesian well flowing continuously with force. The Vayu Purana also refers to the various underground structures and topography such as lakes, barren tracts, dales, rocky rift valley between mountains अन्दद्धोणी (38.36). The chapter 38 of the Purana also speaks of a large number of hot springs in a mountainous region.

तथा ह्यनन्त तप्तानि सरांसि द्विज सत्तमाः ।

शैलकुक्ष्यन्तरस्थानि सहस्राणि शतानि च ॥ Vayu.38.78 ॥

The Gopath Brahmana was also acquainted with two types of springs or falls, namely hot and cold (II,8).

As mentioned in the previous chapter, in Markandeya Purana we come across a peculiar type of topography found in the Kimpurusavarsa and seven other countries where water bubbles up from the ground (55.21-22).

नवंस्वपि च वर्षेयु सप्त सप्तकुलाचलाः ।

रुकैकस्मिन्स्तथा देशे नद्यश्चाद्रि-विनिः सृता ॥ Markandeya.53.21 ॥

यानि किंपुरुषाघानि वर्षाण्यष्टौ द्विजोत्तम ।

तेषुदिभज्जानि तोयानि नैवं वार्यत्र भारते ।। Markandeya.53.22 ।।

The above discussions reveal that chapter 54 of the Vrhata Samhita is a very important treatise on ground water exploration.

Epilogue:

Discussions and the references presented in the chapter show that there were well developed scientific concepts of groundwater occurrence, distribution, prospecting and utilization. It is for this reason that the people of Harappan civilization were able to dig the wells and able to utilize the groundwater. By means of hydrologic indicators such as physiographic features, termite mounds, geophysical characteristics, soils, flora, fauna, rocks and minerals etc., the presence of ground water was detected, which is fully scientific. Termite mounds were used as an important indicator of the groundwater by the ancient Indians. The presence and variation of these indicators have been linked up with the availability of underground springs in modern era too. Modern scientists have also established that the moisture within the mounds is kept practically at saturation level (99-100%) indicating the presence of underground spring in proximity. Well before many centuries of Christ, Indians were aware of underground water bearing structures, change in the direction of flow of ground water, high and low water tables at different places, hot and cold springs, ground water utilization by means of wells, well construction methods and equipment, underground water quality and even the artesian well schemes. This high level of knowledge of groundwater in those ancient times was developed by indigenous people of India altogether independently.

WATER QUALITY AND WASTE WATER MANAGEMENT

Throughout the history, the use of water has reflected various experiences and interpretations of and values about health, illness and well being. The idea that water reflects a harmony between the physical, social and ecological environment can already be found in ancient medicine. As long as 4,000 years ago, the Indians were having the knowledge of purifying the water through boiling. Later, Hippocrates was known to use both water filters and boiling to improve water quality (UNESCO, IHP, 2011). The modern scientists at one time, used to consider rainwater as pure like distilled water. But later studies revealed that it is not so. The water of precipitation is characteristically the purest water in the hydrological cycle, but even so it may collect from less than 1 to several hundred milligrams of dissolved material per litre of water during its fall through the atmosphere. Rainwater, as it falls to the earth, has ample opportunity to dissolve gases from the air and may also dissolve particles of dust or other air borne materials. Thus, rain water becomes a mixed electrolyte containing varying amounts of major and minor cations and anions. Sodium, potassium, magnesium, calcium, chloride, bicarbonate and sulphate are the major constituents. Ammonia and various nitrogen compounds are generally present. Dust particles are added locally in industrial areas, large population centres and desert areas. Among the land based factors which may be significant in altering the composition of rainwater are the sulphur emitted by volcanoes, fumaroles, springs, and dust particles. Rainwater close to the ocean commonly contains from 1.0 milligram per litre to several tens of milligrams per litre of chloride but the observed concentration generally decreases rapidly in a landward direction.

In Vedas, we get some references to water quality, especially in Atharv Veda. Charaka Samhita, Susruta Samhita (both of pre or early Buddhist era), and Ashtanga Hridaya Samhita (9th century AD) are the repositories of knowledge accumulated on Ayurveda (Science of Life), during the earlier period. In all these ancient standard texts, discourses on water quality constitute an important aspect of Ayurveda. Bhavamisra's Bhava Prakash (16th century AD), which is more or less a compilation of all the Ayurvedic texts of earlier antiquity, also elaborately deals with water quality.

In the Rig Veda, the verse V,83.4 speaks about the tree plantation, forest conservation and yajna (यज्ञ) so as to create pure and healthy environment and good quality of water for well being of mankind as:

प्र वाता वन्ति पतयन्ति विद्युत उदोषधीर्जिहते पिन्वते स्वः ।
इरा विश्वम्भै भुवनाय जायते यत्पर्जन्यः पृथ्वीं रेतसावति ॥ R.V.,V,83.4 ॥

Likewise, verse VII, 50.4 of the Rig Veda also reveals the importance of Yajna (यज्ञ) in relation to purification of water. In Yajur Veda (I,12), we read about the contamination due to combination of substances and about fire as the prime source of purification, by breaking the substances into minute particles, i.e. yanja, heat and sun rays are the agents to purify the water. viz.

पवित्रे स्थो वैष्णव्यौ सवितुर्वः प्रसव उत्पुनाम्याच्छिण पवित्रेण सूर्यस्य रश्मिभिः ।
देवीरापो अग्नेगुवो अग्नेषवो ग्र इममघ यज्ञं नयताग्ने यज्ञपतिं सुधातुं यज्ञपतिं देवयुवम ॥ Y.V.I.12 ॥

In Sam Veda (Previous II.187), we read that the Sun rays cause the rain to come in purest form like white curd as:

इस्मास्त इन्द्र पृश्नयो घृतं दुहत आशिरम ।
एनामृतस्य पिप्पुषी ॥ S.V.P,II.187 ॥

A verse of Atharv Veda (V, 22.5) directs to take preventive measures against the diseases caused by the areas with much grass, high rainfall and bad water quality, viz.

ओकों अस्य मूजवन्त ओकों अस्य महावृषाः ।
यावज्जातस्तक्मं स्तावानसि बल्हिकेषु न्योचरः ॥ A.V.V,22.5 ॥

In the celebrated epic Mahabharata (XII,184.31 and 224.42), we read about the various qualities of water according to its taste. Thus, it is clear that during those days efforts were made to specify the water quality according to its taste.

रसो बहुविधः प्रोक्त ऋषिभिः प्राथियात्मभिः ।
मधुरो लवणस्तिक्तः कषायोम्लः कटुस्तथा ॥ M.B.XII.184.3 ॥

In the Vrhat Samhita, we find many references to water quality in the 54th chapter named “Dakargala”. Verse 54.2 states that ground water should be investigated in relation to its environment.

एकेन वर्णेन रसेन चाम्भरच्युतं नभस्तो वसुधाविशेषात् ।

नानारसत्वं बहुवर्णतां च गतं परीक्ष्यं क्षितितुल्यमेव ॥ Vr.S.54.2 ॥

सशर्करा ताम्रमही कषायं क्षारं धारित्री कपिला करोति ।

आपाण्डुरायां लवणं प्रदिष्टं मृष्टं प्यो नीलवसुन्धरायाम् ॥ Vr.S.54.104 ॥

Soil colour has been described as an indicator of water quality in the Vrhat Samhita (54.104). It says that “pebbly and sandy soil containing copper makes water astringent (कसैला). Brown-coloured soil gives rise to alkaline water, pale white soil to salt water and blue coloured soil makes water pure and sweet”. A water treatment method was also suggested to improve the quality of drinking water as:

अज्जनमुस्तोशीरैः शराजकोशातकामलकचूर्णैः ।

कतकफलसमायुक्तैर्योगः कूपे प्रदातव्यः ॥ Vr.S.54.121 ॥

कलुषं कटुकं लवणं विरसं सलिलं यदि वाशुभगन्धि भवेत् ।

तदनेन भवत्यमलं सुरसं सुसुगन्धि गणैरपरैश्च युतम् ॥ Vr.S.54.122 ॥

The above verses say that a mixture of Anjanam (collyrium, autimony or extract of ammonium), Musta tubers (Nagarmodha), Usira (Khas), Powder of Rajkosataka (Torayi), and Amalaka (आवला), combined with Kataka nuts should be put into a well. If the water is turbid, pungent, saltish, of bad taste and not of good odour, it will be rendered clear, tasty, aromatic, and with other good qualities. Thus, Varahamihira at that time presented a simple method for obtaining potable water from a contaminated source of water. All above plant materials have medicinal value and are commonly available in almost all parts of India. In ancient medical texts such as Charaka Samhita, Susruta Samhita and Astangahradaya Samhita (by Vagbhata), collectively known as Brahattrayi (Great triad), and three other ayurvedic texts Madhavanidanam, Sarangadhara Samhita and Bhavaprakasha, collectively known as Laghutrayi (small triad), some references to water quality are available. In Bhava Prakash many parts have been incorporated from the medical texts of Charaka, Susruta, Vagbhata and the Tantrik texts. The tenth chapter of

Bhava Prakash with 86 verses named as Vari Vargah deals with different aspects of water. Here some aspects of water quality are presented as given in above text (10th chapter, Vari Vargah part) and also analyzed by Prasad (1979). The shloka 2 states the important properties of water and its usefulness for the living beings, as:

पानीयं श्रमनाशनं क्लमहरं मूर्छापिपासाहरं तन्द्राच्छर्दिबन्धहृदलकरं निद्राहरं तर्पणम् ॥ X.2 ॥

Meaning: “the water eliminates the fatigue of the body and mind, destroys weakness. It is good for heart, gives satisfaction, soft, clear, origin of rasas, and destroyer of vomiting, sleeping tendency and constipation”.

In shloka 3 and 4, the classification and nomenclature of different forms of water have been given as:

पानीयं मुनिभिः प्रोक्तं दित्यं भौममित द्विधा ॥ X.3 ॥

दित्यं चतुर्विधं प्रोक्तं धाराजं करकाभवम् ।

तौषारं च तथा हैमं तेषु धारं गुणाधिकम् ॥ X.4 ॥

Water which rains from sky is called ‘Divyam’ and when it gets collected on the earth or as ground water, it is termed as ‘Bhaumam’ by sages. ‘Divyan’ water is divided in four categories: ‘Dharajalam’ falls as continuous shower from sky, ‘Karakabhavam’ when it falls like the pieces of stones, ‘Tausaram’ is free from the smoke etc. and ‘Haimam’ is caused from the snow of Himalayas. Among these ‘Dhavajalam’ is better, having full of qualities.

Similarly, shloka 25 gives classification of Terrestrial water (Bhauma Jalam).

भौमयभयौ निगदित्वं प्रथमं त्रिविधं बुधैः ।

जागडलं परमानूपं ततः साधरणं क्रमात् ॥ X.25 ॥

It means, “the Bhaum Jalam is of three varieties viz. Jangalam, Anupam, and Sudharanam. Above water divisions are based on the characteristics of the regions which are differentiated according to their environmental conditions, as:

अल्पोद कोल्पवृक्षश्च पित्तरक्तामयान्वितः ।
ज्ञातव्यो जागडलो देशस्त्रत्यं जांगलं जलम् ॥ X.26 ॥

बहम्बुर्वहुवक्षश्च वातश्लेष्मामयान्वितः ।
देशोनूप इति ख्यात आनूपं तदभवं जलम् ॥ X.27 ॥

मिश्रचिन्हस्तु यो देशः सहि साधारणः स्मतः ।
तस्मिन्देशे यदुदकं तन्तु साधरणं स्मृतम् ॥ X.28 ॥

जागडलं सलिलं रक्षं लवणं लघु पित्तनुत ।
वह्निकत्कफहृत्पथ्यं विकारन हरते बहून् ॥ X.29 ॥

आनूपं वार्यभिष्यन्दि स्वादु स्निग्धं धनं गुर ।
साधरणं तु मधुरं दीपनं शीतलं लघु ।
तर्पणं रोचनं तृष्णादाहदोषत्रयप्रणुत ॥ X.31 ॥

According to the above verses, the country having sparse trees and less water and having bad effect of causing pitta and vata disorders are the Jangala region and water originated in this region is termed as Jangala water. The region having plenty of water and abundant trees and able to cause Vata and Kapha diseases is called Anupam and its water as Anupam water. The regions having mixed characteristics of above two types is called Sadharanam region, and its water is called Sadharana Jalam. Jangala water is saltish, soft, eliminates Pitta and Kapha, promotes digestion, and a good diet in diseases. Anupa water is tasty, oily, viscus, hard, retards digestion, promotes Kapha and is a creator of other disorders. Sadharana Jalam is sweet, promotes digestion, soft, cool, pleasant and eliminates tridosa (three diseases). Thus, we see here that in the study of water, a large number of factors of ecology have also been considered.

Water Quality Standards

In the various reference quoted above, at various places, we come across the words such as विशदं (clear, clean, pure, pellucid, etc.), स्वच्छम् (clear), निर्दोष (blemishless), कलुषं (polluted) and निर्मलत्वं (unpolluted).

Shlokas 78-81 describe the characteristics of the contaminated water as:

पिच्छिलं कृमिलं क्लिन्नं पर्णशैवालदकर्मैः ।
विवर्णं विरसं सान्द्रं दुर्गन्धं न हितं जलम् ॥ X.78 ॥

कलुषं छन्नमम्भोजपर्णनीलीतृणादिभिः ।
दुः स्पर्शनमसंस्पृष्ट सौरचान्द्रमरीचिभिः ॥ X.79 ॥

अनार्तव्यं वार्षिकं तु प्रथमं तच्च भूमिगम ।
व्यापन् परिहर्तव्यं सर्वदोषप्रकोपणम् ॥ X.80 ॥

तत्कुर्यात्स्नानपानाभयां तृष्णाध्मानचिरज्वरान् ।
कासाग्निमांघाभिष्यन्दकण्डूगण्डादिकं तथा ॥ X.81 ॥

According to these verses “waters which are of sticky nature, containing worms and spoilt by leaves and mud, of bad colour, thick, of bad smell, are not good for health. Muddy water and water covered by lotus leaves, grass etc., un-illuminated by sunlight or moonlight, lacking movement, caused by untimely rain or the first rain water which gets collected in the ground, such waters are the source of many disorders. Thus, they should be prohibited because the use of such waters for drinking and bathing purposes, cause तृषा, आध्यामान्, जीर्णज्वर, अग्नमान्द, कण्डू, गण्डा and so on. A critical study of other shlokas also clearly reveals the approach of ancient Indians for water quality standard for different uses.

Variation in the quality of water with seasons, as also from different sources, has been explained in shlokas 59-67.

हेमन्ते सारसं तोयं ताड़ागं वा हितं स्मृतम् ।
हेमन्ते विहितं तोयं शिशिरेपि प्रशस्यते ॥ X.59 ॥

वसन्तग्रीष्मयोः कौप वाप्यं वा निर्झरं जलम् ।
नादेयं वारि नादेयं वसन्तग्रीष्मयोर्बुधैः विषवद्वनवृक्षाणां पत्राघैर्दूषितं यतः ॥ X.60 ॥

औदभिन्द चान्तरिक्षं वा कौपं वा प्रावपि स्मृतम् ।
शस्तं शरि नादेयं नीरमंशूदकं परम् ॥ X.61 ॥

दिवा रविकरैर्जुष्ट निशि शीतकरांशुभिः ।
ज्ञेयमंशूदकं नाम स्निग्धं दोषत्रयापहम् ॥ X.62 ॥

अनभिष्यन्दि निर्दोषमान्तरिक्षजलोपमम् ।

बल्यं रसायनं मेध्यं शीतं लघु सुधासमम् ॥ X.63 ॥

शरदि स्वच्छमुदयादगस्त्याखिलं हितम् ॥ X.64 ॥

पौषे वारि सरोजातं माघे तन्तु तडागजम् ।

फाल्गुने कूपसंभूतं चैत्रे चौज्यं हितं मतम् ॥ X.65 ॥

भाद्रे कौपं पयः शस्तमाश्विने चौज्यमेव च ।

कार्तिके मार्गशीर्षे च जलमात्रं प्रशस्यते ॥ X.67 ॥

Meaning: “water belonging to ponds and tanks during the season हेमन्त (winter, i.e. November–January) are good; during शिशिर (the cool season, i.e. January–March) also the same waters are superior. During बसन्त (Spring, i.e., March–May) and ग्रीष्म (summer, i.e. May–July) the water belonging to wells, stepped deep wells and rocky springs are good. During बसन्त and ग्रीष्म seasons waters of rivers should not be used for drinking because during these seasons the river water becomes contaminated with the leaves of poisonous trees etc. During rainy season aubhida water (ground water of artesian character) or antariksha water (the atmospheric precipitation) are good. During शरद season, waters of the rivers and waters, illuminated by the sun during day time and by the moon during nights, called amsudakam, are good. Ansudak water is destroyer of the Tridosha, not causing abhisyanda and is free from bad qualities. It is equal to akasodakam, good for brain, soft and cool. During शरद season after the rise of star Agastya in the sky all waters become pure. Vriddha Susruta said that during the month of Pusya waters from lakes or ponds, during Magha waters from tanks, during Phalguna waters from wells, during Chaitra Chaunjya (valley stream water), during Vaisakha Nairjhara water etc., during the months of Jyestha the water of artesian character, Asadha the well water and in Kartika and Margasira all kinds of waters are good”.

Factors affecting water quality

As seen from above shlokas of Bhava Prakash, we can identify some factors affecting the quality of water. हेम जलम् i.e. glacial water भौम जलम् i.e. ground water, नाढेय जलम् (river water), औदभिद जलम् (ground water flowing with artesian character), निर्झर (water fall water), तडाग जल pond Water), कौप जल (wells water), चौज्य जल (i.e. valley stream water, Shloka 65) and their qualities have been described in Bhava Prakasha in details, indicating the knowledge of the effect of

geographic condition on the quality of water. These conditions are related to the differences in the earth as अनूप, जांगल and साधारण regions as described before in shlokas 26-27-28. The effect of agricultural soil on water quality (केदार जल, Shloka 57) is also described. viz.

केदारः क्षेत्रमुदिदष्टं कैदारं तज्जलं स्मृतम् ।
कैदारं वायुर्यभिष्यन्दि मधुरं गुरु दोषकृतम् ॥ X.57 ॥

It also describes the effect of decaying vegetation on water quality. Also the effect of stagnation and lack of the penetration of sun light in water, on the water quality have been discussed (Shlokas 78 to 81). These verses show that the modern water quality related concepts were well known during ancient times in India.

The knowledge of the hardness of water has been described in many shlokas (7,19,21,24,29 and 43) quoting the properties of various waters according to origin as:

धारनीरं त्रिदोषध्नमनिर्देश्यकरं लघु ।
सौम्यं रसायनं बल्यं तर्पणं हलादि जीवनम् ॥ X.7 ॥

करकाजं जलं रुक्षं विशदं गुरु च स्थिरम् ।
दारुणं शीतलं सान्द्रं पित्तहृत्कफवातकृत् ॥ X.19 ॥

Here, सौम्यम् (Saumayam) means soft and रुक्षं (ruksam) or दारुणं (darunam) means hard water.

Diseases in relation to water have been described. This is clear from the verses X.27-31, X.78-81 and some other verses. This discourse on water quality and related subjects is quite scientific and shows broad outlook of ancient Indians.

Water Treatment

Shlokas 5 and 6 suggest collection of water in golden, silver, copper and glass vessels or earthen pots, after filtrating from cloth. It reveals the attention paid to get clear water.

सौवर्णे रजते ताम्रे स्फटिके काचनिर्मिते ।
भाजने मृण्मये वापि स्थापितं धारगमूच्यते ॥ X.6 ॥

In shloka 82, we are told that water treatment for drinking purpose should be done by heating or boiling and filtration. Shloka 83 reveals the treatment of water with the aid of heated sand, stones etc. and aromatic materials viz.

निदितं चापि पानीयं क्वथितं सूर्यतापितम् ।
सुवर्णं रजतं लोहं पाषाणं सिकतामपि ॥ X.82 ॥

भ्रशं सन्ताप्य निर्वाप्य सप्तधा सार्धितं तथा ।
कर्पूरजाति पुन्नागपाटलादिसुवासितम् ॥ X.83 ॥

शुचि सान्द्रपटस्त्रवि क्षुत्रजन्तुविवर्जितम् ।
स्वच्छं कनकमुक्ताद्यैः शुद्धं स्याददोषवर्जितम् ॥ X.84 ॥

पर्णमूल विसग्रंथिमुक्ताकनकशैवलैः ।
गोमेदेन च वस्त्रेण कुर्यादबुप्रसादनम् ॥ X.85 ॥

Meaning: “contaminated water can be purified by boiling, by exposure to the sun’s ray or by quenching with fire heated gold, silver, iron, stone or sand and flavouring it with the smell of Camphor, jati (Chameli; Jasminum grandiflorum), Punnaga (Nogkesar; Calophyllum inophyllum), Patala (Padhar; coccinia grandis) etc. and then filtration through clean cloth makes water free from small germs. Purifying it with gold, pearl, etc. also makes it free from pollution. Water should be made free from leaves, roots, stalks of lotus leaves, gold, pearls, cloth etc.”

From above treatment procedure we gather that the positive effects of intense sunlight, heating, filtration, aeration and addition of aromatic components are clearly revealed in the treatise. The bad effects of stagnation of water, contamination of water by leaves, algae etc. are also described. The treatment methods given need no costly inputs and no desirable qualities of water will be changed, which is a measure drawback of the modern chemical methods of water treatment.

Wastewater Management Techniques

Lack of sanitation affects human development to the same or even greater extent as the lack of clean water. While there may be an added stigma to discussing waste treatment, sanitation is widely perceived as meriting a significant claim on financial and political resources as well on

the evolution of mankind. According to Victor Hugo (1892), ‘The history of men is reflected in the history of sewers’. This proverb adequately indicates about the importance of sanitation and wastewater management.

The term sanitation is primarily used to characterize the safe/sound handling and disposal of human excreta as well as other waste products (Avvannavar and Mani, 2008). It is well known that the relationship between humans, water and sanitation has seen substantial changes, due to the influence of cultural, social and religious factors throughout the ages (Sorcinielli, 1998; Wolfe, 1999; De Feo and Napoli, 2007; Avvannavar and Mani, 2008; Lofrano and Brown, 2010). However, all through the ages, wastewater has been considered filthy (Maneglier, 1994; Lofrano and Brown, 2010). The process of evolution of wastewater management through the ages has been discussed by several authors worldwide such as Tarr (1985), Maneglier (1994), Sorcinielli (1998), Viale (2000), Sori (2001), and Neri Seneri (2007). More recently, Lofrano and Brown (2010) have presented an in-depth review of wastewater management in the history of mankind. In this review work they have categorically discussed about the evolution of sanitation through different civilizations of the world, including the ancient Indus civilization.

It would be appropriate to mention Kenoyer (1997) about the new heights of the Indus civilization, *‘that many of the technologies first developed in the Indus cities provided the foundation for later technologies used in South Asia and other regions of the Old World’*. Wastewater management and sanitation were the major characteristics of the first urban sites of the Harappan civilisation (Kenoyer, 1991). Adding to this, Lofrano and Brown (2010) found on records that ‘the Indus civilization was the first to have proper wastewater treatment systems’ in the ancient times. Sewage and drainage were composed of complex networks, especially in Mohenjo-Daro and Harappa. Latrines, soak-pits, cesspools, pipes and channels were the main elements of wastewater disposal. Figure 7.1 shows drainage and sanitation systems of Mohenjo-Daro and Lothal cities of Indus valley civilization.



Figure 7.1: Drainage and sanitation systems of Mohenjo-Daro and Lothal cities of Indus valley civilization (after Khan, 2011; Kenoyer, 1998)

The houses were connected to drainage channels and wastewater was not permitted to flow directly to the street sewers without first undergoing some treatment. First, wastewater was passed through tapered terra-cotta pipes into a small sump. Solids settled and accumulated in the sump, while the liquids overflowed into drainage channels in the street when the sump was about 75% full (Lofrano and Brown, 2010). The drainage channels could be covered by bricks and cut stones, which probably were removed during maintenance and cleaning activities (Wolfe, 1999). Further, cesspits were fitted at the junction of the several drains or where a drain was extended for a long distance in order to avoid the clogging of the drainage systems (Wright, 2010). Fardin et al. (2013) found that almost all the settlements of Mohenjo-Daro were connected to the drain network.

In Jorwe, in present day Maharashtra, it has been demonstrated that the drainage system was implemented from 1375–1050 BC (Kirk, 1975; Fardin et al., 2013). Later (around 500 BC),

Ujjain's 'drainage system included soak-pits built of pottery-ring or pierced pots' (Kirk, 1975), and it has been supposed that ring-wells were used for the disposal of wastewater (Mate, 1969). In the 3rd century BC at Taxila, domestic wastewater was canalized out from the houses through earthenware drain-pipes into soak-pits (Singh, 2008). During 1st century BC, drains were being used for sewage disposal in Arikamedu, the southern part of India (Casal, 1949). Further, the wastewater systems were improved around 150AD with the use of corbelled drains (Begley, 1983). Bhardwaj (1997) found that this system was draining water from basins supposed to be a part of a textile and dye industry. This was the unique feature associated with this system as compared to the rest of ancient India, where the wastewater disposal was implemented for domestic effluents only.

Epilogue

From the above discussions it can be concluded that during the ancient times, modern concepts of water quality, sanitation and waste water management technology were very well known to the Indians and were in their advanced stages during the Indus valley civilization and later periods. Water classification and viewing its quality in relation to environment satisfies the modern concept of ecology. Water quality standards, factors affecting water quality, effect of decaying materials on quality of water, lack of aeration in stagnating and deep water bodies etc. were known which are in accordance to modern science. Water treatment methods using filtration, pots of different materials like earthen, silver, gold etc., quenching with hot stones, sun heating, aeration, addition of aromatic compounds etc. were adopted. These methods are frequently used even now-a-days and are better than the chemical disinfectants as there is no change in the desirable qualities and odours of water. Modern methods of wastewater disposal systems based on centralized and decentralized concept as well as methods for wastewater treatments during Indus valley civilization were even better than those used in the contemporary world.

WATER RESOURCES UTILIZATION, CONSERVATION AND MANAGEMENT

As in many other parts of the world, civilization in India also flourished around rivers and deltas, and rivers remain an enduring symbol of national culture. As has been mentioned earlier, the Indus Valley civilization, one of the earliest civilizations, was the world's largest in extent, had great and well planned cities with public and private baths, sewerage through underground drains built with precisely laid bricks, and an efficient water management system with numerous reservoirs and wells. Agriculture was practised on a wide scale, with extensive networks of canals for irrigation. Irrigation systems, different types of wells, water storage systems and low cost and sustainable water harvesting techniques were developed throughout the region at that time (Nair, 2004). The Rig Veda clearly mentions about the life style, social structure, agriculture and crops grown by the society at that time. Irrigation channels and kuccha and pucca wells are also mentioned in different hymns (R.V. 19.4.2/RX2.9.4) (Bagchi and Bagchi, 1991). Agriculture and livestock rearing occupied a prominent role during Jainism and Buddhism period and channel irrigation was in vogue (Bagchi and Bagchi, 1991). McClellan III and Dorn (2006) state that 'the Mauryan empire was first and foremost a great hydraulic civilization'. This shows the degree of knowledge about efficient utilization of water resources and their conservation for the welfare of the society during that time.

During Mauryan period, raingauges were installed in different parts of the country to have areal information of the rainfall and based on the information supplied, the 'Superintendent of Agriculture' gave directions for sowing the seeds in different parts of the country (Srinivasan, 1975). Almost all ancient civilizations were confined to the areas of reliable water resources, revealing the importance of water for development from very ancient days. During the time of Rig Veda, we get many references to water use by means of rivers, wells, ponds etc. for agriculture, domestic and other purposes. Verse I, 121.8 of Rig Veda reveals the same fact as:

अष्टा महोदिव आदो हरी इह घुम्नासाहमभि योधान उत्सम् ।

हरिं यत्ते मन्दिनं दुक्षन्वृधे गोरभसमद्रिभिर्वाताप्यम् ॥ R.V.I,121.8

Similarly verses (I,23.18 and V, 32.2) state that the agriculture can be progressed by use of water from wells, ponds etc. wisely and efficiently. The verse (VIII,3.10) of Rig Veda says about the construction of artificial canals to irrigate desert areas also, which is possible only by efforts of skilled persons (Ribhus/engineer) as:

येना समुद्रमसृजो महीरयस्तदिन्द्र वृष्णि ते शवः ।

सघः सो अस्य महिमा न सन्नशे यं क्षोणरिनुचक्रदे । R.V.VIII,3.10 ॥

उतनों दित्या इष उत सिन्धुरहर्विदा ।

अप द्वारे व वर्षथः ॥ R.V.VIII,5.21 ॥

Verses (VIII, 49.6; X64.9) speak about the importance of water for irrigation. The water from wells, rivers, rain and from any other sources on the earth should be wisely used as it is a gift of nature for well-being of all.

उद्रीव वज्रिन्नवतो न सिज्वते क्षन्तीन्द्र धीतयः ॥ VIII,49.6 ॥

सरस्वती सरयुः सिन्धुरुर्मिमिर्म हो महीरवसा यन्तु वक्ष्णीः ।

देवीरापो मातरः सूदयित्वो घृतवत्पयो मधुमन्नो अर्चत ॥ X.,64.9 ॥

Similar to Rig Veda, Yajur Veda also contains references, directing the man to use rain and river water by means of wells, ponds, dams and distribute it to various places having need of water for agriculture and other purposes as:

नमः स्त्रुत्याय च पथ्याय च नमः काट्याय च नीप्याय च ।

नमः कुल्याय च ररस्याय च नमो नदेयाय च वैशन्ताय च ॥ Y.V.,16.37 ॥

In the Atharva Veda, we have references to drought management through efficient use of available water resources and water conservation. It clearly says that the water of river, well etc., if used efficiently, will reduce the intensity of drought, viz.

आपो यद् वस्तपस्तेन तं प्रति तपत यो स्मान् द्धेष्टि यं वयं द्विष्मः ॥ A.V.II,23.1

Verses VI, 100.2 and VII,11.1 of the Atharva Veda explains that the learned men bring water to desert areas by means of well, pond, canals etc. (VI,100.2). It also stresses that the man should think about the drought, flood and like natural calamities in advance and take preventive measures accordingly as:

यद् वो देवा अपजीका आसिंज्वन धन्वन्युदकम् ।
तेन देव प्रसूतेनदं दूषयता विषम् ॥ A.V.VI,100.2 ॥

Verse XII,1.3 of the Atharva Veda explains that those who use rainwater wisely by means of river, well, canals etc. for the purposes of navigation, recreation, agriculture etc., prosper all the time as:

यस्था समुद्र उत सिन्धुरापो यस्यामत्न कृष्टयः संवभूवुः
यस्यामिदं जिन्वति प्राषदेजत सा नो भूमिः पूर्व पेयं दधातु ॥ A.V.XII,1.31 ॥
शंत आपो हेमवतीः शमु ते सन्तु वर्ष्याः ।
शं ते सनिष्पक्ष आपः शमु ते सन्तु वर्ष्याः ॥ A.V.19.2.1 ॥

Meaning: “That one should take proper managerial action to use and conserve the water from mountains, wells, rivers and also rainwater for use in drinking, agriculture, industries etc.”

Similarly, one verse of the Atharva Veda (XX,77.8) directs the king to construct suitable canals across mountains to provide water for his subject for agriculture, industry etc. and to facilitate navigation between two areas as:

आपो यदद्रि पुरुहूत दर्दराविर्भुवत् सरमा पूर्य ते ।
स ना नेता वाजमा दर्षि भूरि गोमा रुजन्नगिरोभिर्गृणान ॥ A.V.XX,77.8 ॥

Water Resources Management

India has a fascinating and significant ancient tradition of conserving land and water and even today, local people follow several such traditional conservation practices. As discussed in the beginning of this chapter, out of the agricultural necessity, the science of water management was given considerable importance during ancient India. During Mauryan era, the Pynes and Ahars (the combined irrigation and water management system) in Magadh region were effective water

engineering tools. Ahars were reservoirs with embankments on three sides, built at the end of drainage lines such as rivulets or artificial works like Pynes. Pynes were diversion channels led off from the river for irrigation purposes and for impounding water in the Ahars. As a representation, the Pyne-Ahar system is shown in Figure 8.1.



Figure 8.1: Ahar Pyne system in Gaya, South Bihar

(Image courtesy: Hindi Water Portal; <https://www.thebetterindia.com/6963/tbi-videos-magadh-jal-jamaat-helps-revive-2000-year-old-flood-water-harvesting-systems-in-gaya-bihar/>)

Agricultural planning was common so as to manage the rainfall excess or deficit. It is very well elaborated in Arthashastra as: “according to the rainfall (more or less) the superintendent of agriculture shall sow the seeds which require either, more or less water”. Kautilya says that “king should construct dams, reservoir etc. filled with water either perennial or drawn from some other source or he may provide with sites, roads, timber and other necessary things to those who construct reservoir of their own accords (Arthashastra, Tras. By Samsastry, Book II, Chapt. 1, page. 46). He further says that the king shall exercise his right ownership (स्वाम्यम्) with regard to fishing, ferrying and trading of vegetables in Reservoirs or lakes (सेतुषू)”.

During this period, embankments were constructed surrounding the fields to increase the water holding capacity. Dams were constructed at strategic points with sluice gates to harness river

water with proper regulation facilities. Conduits were also constructed at that time to attain better efficiency in irrigation (Bagchi and Bagchi, 1991). Figure 8.2 shows the Sudarsana lake, Junagadh constructed during the reign of Chandragupta Maurya, by the provincial governor, the Vaisya Pusyagupta; and subsequent improvements involving the addition of conduits during the reign of Asoka, by his provincial governor, the Yavana king Tusaspha (Shaw and Sutcliffe, 2010; Kielhorn 1905-6, p. 41).



Figure 8.2: A view of Sudarsana lake Girnar, Junagadh, Gujarat
(Source: <https://junagadh.gujarat.gov.in/photo-gallery>)

Recently, Sutcliffe and Shaw (2011) explored the Sanchi site (a well-known Buddhist site and a UNESCO World Heritage site) in the Betwa river sub-basin (a tributary of Yamuna in Ganga basin) in Madhya Pradesh. They found a number of dams equipped with spillways. They found that these dams would have been built on the basis of a sound knowledge of the principles of water balance. In addition to the design of the reservoirs, the presence of spillways on at least two of the larger dams, which would pass floods of about 50 years' return period, suggests that flood protection was also taken into account. The Arthashastra of Kautilya also gives us an extensive account of dams and bunds that were built for irrigation during the period of the Mauryan Empire. The water supply systems were well managed within the framework of strict rules and regulations. Specifically, an organized water pricing system, which is an important part of water management, was also developed during this period as evidenced by following lines of

Arthasastra: “those who cultivate irrigating by manual labour (हस्ताप्रवर्तिमाम्) shall pay 1/5 the produce as water rate (उदकाभागम्); by carrying water on shoulders (स्कन्धाप्रावर्तिमाम्) = (water lift worked by bullocks), 1/4th of the produce; by water lifts (स्त्रोतोयंत्राप्रवर्तिमाम्) 1/3rd of the produce; and by raising water from rivers, lakes, tanks and wells (नदिसरासततकाकुपदाहाटम्) 1/3rd or 1/4th of the produce (Arthasastra, Tras. By Samasastry, Book II, Chapt. XXIV page 131)”.

In Vrhat Samhita, we get a few references regarding the orientation of ponds so as to store and conserve water efficiently, plantation types for bank protection and proper sluicing to protect reservoir from any possible damage as:

पाली प्रागपारायताम्बु सुचिरं धत्ते न याम्योत्तरा
कल्लोलैखदारमेति मरुता सा प्रायशः प्रेरितैः ।
तां चेदिच्छति सारदारुभिरपां सम्पातमावारयेत
पाषाणदिभरेव वा प्रतिचयं क्षुण्णं द्विपाश्वादिभिः ॥ Vr. S. 54.118 ॥

Meaning: a pond laid east to west retains water for a long time while one from north to south is spoilt invariably by the waves raised by the winds. To render it stable, the walls have to be lined with timber or with stone or the like and the adjoining soil strengthened by stamping and trampling of elephants, horses etc.

ककुभवटाम्रप्लक्षदम्बैः सनिचुलजम्बूवेतसनीपैः ।
कुरबकतालाशोकमधूकैर्बकुलविमिश्रैश्चावृततीराम ॥ Vr.S.54.119 ॥

Meaning: the banks must be shaded by Kakubha Vata, Amra, Plasa, Kadamba, Nicula, Jambu, Vetasa, Nipa, Kuravaka, Tala, Asoka, Madhuka and Bakula trees.

In next verse (Vr.S.54.120), it directs the construction of spillway as:

द्वारं च नैर्वाहिकमेकदेशे कार्यं शिलासिज्जतवारिमार्गम् ।
कोशास्थितं निर्विवरं कपाटं कृत्वा ततः पांशुभिरावपेत्तम् ॥ Vr.S.54.120 ॥

Meaning: an outlet for the water has to be made on a side with the passage being laid with stones. A panel without apertures has to be fixed in a frame, which is fastened to the earth with mud and clay.

From this discourse, we can realize that the water management was getting due importance in ancient India and even bank protection, spillway etc. and other minor aspects were given due consideration.

In ancient India much attention was also paid to the proper location of artificial tanks. Various techniques were applied and equally different materials were utilized for the construction of works. It appears that special works for treatise on science of hydrology must have existed in south India. The Porumamilla tank inscription of Bhaskara Bhavadura dated A.D. 1369 throws an abundant light on the elaborate method of construction of tanks and dams in the south India.

Constituents of a good tank are well described in ancient literature. According to the Sastra (Epigraphia Indica, Vol, PP. 108, Quotes from Hemadri, Verses 37-38, Srinivasan T.M., 1970), the following are the 12 essentials of a good tank as: (i) A king endowed with righteousness, rich, happy and desirous of the permanent wealth and fame; (ii) Brahmana learned in hydrology (Pathas-Sastra); (iii) Ground adorned with hard clay; (iv) A river conveying sweet water (and) three Yojanas distance from its source; (v) The hill, parts of which are in contact with tank; (vi) Between (these portions of the hill) a dam (built) of a compact-stone wall, not too long but firm; (vii) Two extremes (Srimga) pointing away from fruit (giving) land (Phala-Sthira) outside; (viii) The bed, extensive and deep; (ix) A quarry containing straight and long stones; (x) The neighbouring fields, rich in fruit and level; (xi) A water course (i.e., the sluice) having strong eddies on account of the portion of the mountain (adri-sthana); and (xii) A gang of men (skilled in the art of its construction). With these 12 essentials, an excellent tank is easily attainable on this earth.

From these points on comparison with the modern, science of water management regarding construction of dams and reservoirs, we will find that the technique in those days was just comparable to the modern sophisticated engineering, as far as general requirements are concerned. Along with these 12 essentials, six faults were also recognized which will reduce the usefulness of the reservoir and water conservation will become difficult. These faults (Dosas) are as follows (Epigraphia Indica, Vol. XIV, PP. 108, Quotes from Hemadri, Verse 39, through Srinivasan T.M. (1970) as:

- (i) Water oozing from the dam
- (ii) Saline soil

- (iii) Situation at the boundary of two kingdoms
- (iv) Elevation (Kurma) in middle (of the tank) bed
- (v) Scanty supply of water and extensive stretch of land (to be irrigated), and
- (vi) Scanty ground and excess of water

Epilogue

The above discussion brings out that water use by means of wells, ponds, tanks and canals was prevalent during the ancient times, along with the efforts to supply water in deserts also. Organized water pricing system was prevalent and preventive measures against natural calamities such as floods, drought etc. was common. Construction methods and materials of dam and ponds, essential site and other requirements of good tanks, bank protection spillways etc. were paid sufficient attention. High level of development was achieved in the areas of proper location and orientation of tanks, lining of banks, evapotranspiration control, drought management, etc. Thus, ancient India was at a high plane of development in the field of engineering in irrigation and water conservation. State-of-the-art irrigational facilities were established during the ancient times in India for increasing agricultural produce apart from improved drinking water supplies for the people. Ancient India was highly progressive in the area of water management. Such remarkable development in the absence of scientific instruments of the ancient times invokes astonishment and admiration of the readers.

CONCLUDING REMARKS

Water is most precious and critical natural resource for survival of all the living beings. It has been so intimately linked to our very existence and societal and cultural developments that it has become the source of rich symbolism, traditions, rituals and religious beliefs. Water played a pivotal role in shaping the life and living standards of the people of the great civilizations of the world. Throughout history, our vital relationships to water have led to material testimonials of how water was used, managed and valued. The first successful efforts to control the flow of water were mainly driven by agricultural needs for irrigation purposes. With a more detailed understanding of the hydrologic cycle, nature of surface water, ground water and rain water; robust and sustainable water management systems were also evolved in all the civilizations that prospered for thousands of years.

Besides the spiritual growth, ancient India also exhibited the growth of science. The Indus Valley Civilization, one of the earliest and most developed civilizations, was the world's largest in extent and epitomises the level of development of science and societies in proto-historic Indian sub-continent. As rightly observed by Jansen (1989), the Indus people were known for their obsession with water. They prayed to the rivers everyday and gave them a divine status. Ancient Indian literature, dating back from the age of the Vedas, further witnesses this development of sciences (including the water science). Numerous references exist in Vedic literature, Arthashastra, Puranic sources, Vrat Samhita, Mayuracitraka, Meghmala, Jain, Buddhist and other ancient Indian literature which illustrate the status of the knowledge of hydrology and water resources in ancient India.

As we investigate deeper into hydrologic references in Indian mythology, many fascinating dimensions of the early scientific endeavours of mankind emerge. Fortunately, the ancient Indian works have been well documented and provide us with pointers to the human history in general, and growth of water sciences in India in particular. Number of research works related to water science developments in ancient India have been also published by national and international research community. While updating this book, an attempt has been made to incorporate a number of recent national as well as international research papers and technical book published by various national and international institutions. Figures illustrating various concepts,

hydrological processes and water engineering techniques have also been included to clarify the concepts and help forming clear mental image of the developments.

What is less known, however, is the rigorous discussion in the Vedic literature and other ancient Indian literature on several aspects of hydrologic processes and water resources development and management practices as we understand them today. It is high time that we realize and question our current systems of water resources utilization and management and acknowledge our traditional wisdom and practices and apply them to the modern context. Hence, a comparison of hydro-technologies in ancient times to that of the modern times is required. Although to some extent, there are differences in the tools and techniques used today and the scale of applications, still there are no differences in the fundamental principles used. Even the lifestyle related to the hygienic standards of a civilization may not be a recent development. For example, flushing toilets equipped with seats resembling present-day toilets and drained by sewers has existed during ancient times.

Finally, in view of our immense traditional knowledge in water science and technology, it is important and helpful to study and represent the connection between water and humans more deeply as was prevalent in India during ancient times.

BIBLIOGRAPHY

A: Primary Sources:

1. Rig Veda Samhita (3000 B.C.), (i) Bhasya by Maharshi Dayananda Saraswati (Hindi), Published by Dayananda Sansthan, New Delhi-5.
(ii) Bhasye by Swami Satyaprakash Saraswati (English), Published by Veda Pratisthan, New Delhi.
2. Sam Veda (3000 B.C.) Bhasya by Swami Dayananda Saraswati, Published by Dayananda Sansthan, New Delhi-5.
3. Yajur Veda (later than Rig Veda), Bhasya by Swami Dayananda Saraswati, (Hindi) Dayananda Sansthan, New Delhi-5.
4. Black Yajur Veda (Taithiriya Sanhita) (Later than Rig Veda), Edited by Pt. Shripad Damodar Satvalekar, Swayadhya Mandal, Maradi, Disit. Balsod, Gujara.
5. White Yajur Veda (Vajasaney Sanhita) (Later than Rig Veda, English Trans. By R.T.H. Griffith, Munsiram Manohar lal Publishers, Rani Jhansi Road, New Delhi, 1987.
6. Atharva Veda (the latest Veda), Bhasya by Pt. Khem Karan Das Trivedi, Sarvadeshik Arya Pratinidhi Sabha, Maharshi Dayananda Bhavan, Ramlila Maidan, New Delhi.
7. Satapatha Brahmana (2000 B.C.), Edited by Pt. Ganga Prasad Upadhyaya. The Research Institute of Ancient Sanskrit Studies, New Delhi-8.
8. Gopatha Brahmana (much later than 1000 B.C.), Bhasya by Pt. Khem Karan Das Trivedi, Edited by Dr. Prajna Devi and Medha Devi, Published by Atharvaveda office, 34, Lukarganja, Allahabad, 1977.

Epics:

9. The Vaimiki Ramayana (800 B.C. to 200 B.C.), Gita Press, Gorakhpur, in two volumes with Hindi translation.
10. The Mahabharata (400 B.C. to 400 A.D.) Translated by Pt. Ramanarayana Datta Shastri, Pandeya 'Ram' Gita Press, Gorakhpur in six volumes.

Smriti:

11. Manusmriti (200 B.C. or earlier than that), Edited by Pt. Haragovinda Shastri, Chowkhamba Sanskrit Series Office, Varanasi -221 001, 1984.

Philosophical System:

12. Vaisheshika Sutra of Kanada (Pre-Buddhist, 600-700 B.C.), Translated by A.E. Gough, Oriented Books Reprint Corporation. 54, Rani Jhansi Road, New Delhi-110 055, 1975.

Grammar:

13. Panini's Astadhyayi (700 B.C.), Bhasya by Brahmadatta Jijnasu, published by Ramlal Kapoor Trust, Nahalagarh, Sonapat, Haryana, 1985 two volumes.

Polity:

14. Arthashastra (Kautilya, 400 B.C.), Ed by R. Shamashastri, Eng. Trans: Ibid. Mysore printing and publishing House, Mysore, 1967.

Puranas (6th century B.C. to 700 A.D.):

15. Brahmanda purana (3rd, 4th century A.D.) Edited by Dr. Chamana Lal Goutam, Published by Sanskrit Sansthan Ved Nagar, Bareilly-243 003, two volumes, 1988.

16. Garuda Purana, published by Tejkumar Book Depot Pvt. Ltd. Lucknow-26001, 1989.
17. Kurma Purana, Edited by Pt. Shri Ram Sharma, Sanskrit Sansthan, Ved Nagar, Bareilly, two volumes, 1986.
18. Linga Purana, Ibid. 1987.
19. Markandeya Purana, Hindi Trans. By Dr. Dharmendranath Shastri, Sahitya Bhandra, Subhash Bazar, Meerut-250 002, First Edition, 1983.
20. Matsya Purana (6th century B.C. to 4th century A.D.), Edited by Pt. Shri Ram Sharma, Veda Nagar, Breilly (UP), two volumes, 1989.
21. Narada Purana, Ibid., 1984.
22. Padma Purana, Ibid., 1986.
23. Skanda Purana, (7th century A.D.), Ibid. 1988.
24. Vayu Purana, Hindi Trans. By Rama Pratap Tripathi Sastri, Hindi Sahitya Sammelan Prayag, 12, Sammelan Marg., Allahabad, 1987.
25. Visnu Purana: Same as 24th above, 1989.

Astronomical Works:

26. Vrhata Sanhita (550 A.D.) by Varahamihira, Edited and Bhasya by Pt. Achyutanada Jha, Chow Khamba Vidyabhawan, Varanasi-221 001 1988.
27. Mayurcitarka (Nardiya), Manuscript No. 34332, Kept at Saraswati Bhavan Library of Sampurnananda Sanskrit University, Varanasi.
28. Meghamala (around 900 A.D.), Manuscript No. 37202, Kept at the Saraswati Bhavan Library of above University.

Others:

29. Meghadutam of Kalidas (100 B.C.), Bhasya by Malinath, Edited by Dr. Jaya Shankar Tripathi, devabhasa Prakashan, Allahabad-6.
30. Kalidas Granthavall: Edited by Sitaram Chaturvedi, Chowkhamba Prakashan, Varanasi, 1980.
31. Mrcchakatika of Sudraka (6th Century A.D.), Hindi Trans. By Dr. Shrinivasa Shastry, Sahitya Bhavana, Subhash Bazar, Meerut (UP), 1980.
32. Bhava Prakash Nighantu by Bhava Mishra (16th century A.D.), with Commentary of Pt. Vishvanath Dwivedi Shastri, Motilal Banarasi Das publishers, Delhi-7 1988.

B: Secondary Sources:

33. Baker, B.N. and Horton, R.E. (1936). Historical Development of Ideas Regarding the Origin of springs and Ground Water, Trans of American Geophysical Union, Vol. 17, pp. 395-400.
34. Biswas, A.K. (1967). Hydrologic Engineering prior to 600 B.C. Jr. of the Hydraulic Division, ASCE, Vol. 93, Hy. 5, pp. 115-135.
35. Biswas, A.K. (1969). Science in India, Firma K.L. Mukhopadhyaya, Calcutta, 154 p.
36. Biswas, A.K. (1969). History of Hydrology, North Holland Pub. Co., Amsterdam, London, 336 p.
37. Chow, V.T. (1964). Hand Book of Applied Hydrology Mcgrew-Hill Company, New York.
38. Law, B.C. (1984). Historical Geography of Ancient India, Munshiam Manoharlal, New Delhi.

39. Pannikar Raimundo, (1977). *The Vedic Experience Mantra-Manjari* Motilal Banarsidas, Delhi.
40. Parkhe, M.S. and Vasant, (1989). Yajna Krishi, *Rasayanik Kheti ka Vikalp*, Sthayi Vikas, Patrika, No. 1, Vol.3, 1989, pp.9-11.
41. Prakash, S. (1965). *Founders of Sciences in Ancient India*, The Research Institute of Ancient Scientific Studies, New Delhi.
42. Prasad, E.A.V. (1979). *Water Quality in Bhavamsira's Bhava Prakasa*, MASSLIT Series No.2, N.J. Publications, Tirupathi.
43. Prasad, E.A.V. (1980). *Ground water in Varahamihira's Vrahat Sanhita*. MASSLIT series No.1, Sri Venkateswara University Press, Tirupathi, India.
44. Prasad, V.T. B.S. Kumar, and S. Kumar, (1987). *Water Resources Development in India – Its Central Role in the past and Crucial Significance for Future*, Proc. Of the International Symposium on Water for Future, IAHR, Rome, pp. 19-34.
45. Rao, E.G.K. Kotekar, P.O. (1971). *Exploration of Underground Water Springs According to the Ancient Hindus*, Indian Jr. of History of Sciene, Vol. 6, No.2, P.139-146.
46. Seal, B.W. (1958) *Positive Sciences of Ancient India*, Motilal Banarasidass, New Delhi.
47. Sircar, D.C. (1971). *studies in the Geography of Ancient and Medieval India*, Motilal Banarasidass, New Delhi.
48. Srinivasan, T.M. (1970). *A Brief Account of the Ancient Irrigation Engineering Systems Prevalant in South India*, Indian Jr. of History of Science, Vol.5, No.2 1970, pp. 315-325.
49. Tripathi, M.P. (1969). *Development of Geographical Knowledge in Ancient India*, Bhartiya Vidya Prakashan, Varanasi-1, India.
50. Varshney, R.S. (1979) *Engineering Hydrology*, Nemchand and Bros., Roorkee (UP).
51. Shirsath, P.B. (2009). *Irrigation Development in India: History & Impact*, Water Technology Centre, WTC, IARI, New Delhi, http://indiairrigation.blogspot.com/2009/01/history-of-irrigation-developmentin_01.html.
52. McClellan, III. J.E. and Dorn, H. (2006). *Science and Technology in World History: An Introduction*. IInd Edition, the Johns Hopkins University Press 2715 North Charles Street Baltimore, Maryland 21218-4363.
53. Vuorinen, H.S. Juuti, P.S., and Katko, T.S. (2007). *History of water and health from ancient civilizations to modern times*. *Water Science & Technology: Water Supply* Vol. 7 No. 1 pp. 49–57.
54. Yannopoulos, S. I. Lyberatos, G. Theodossiou, N. Li. W., Valipour, M. Tamburrino, A. and Angelakis, A.N. (2015). *Evolution of Water Lifting Devices (Pumps) over the Centuries Worldwide*. *Water* 2015, 7, 5031-5060; doi:10.3390/w7095031.
55. Scarborough, V.L. (2003). *The Flow of Power: Ancient Water Systems and Landscapes*; School of American Research Press: Santa Fe, NM, USA, p. 204.
56. Ortloff, C.R. (2009). *Water Engineering in the Ancient World—Archaeological and Climate Perspectives on Societies of Ancient South America, the Middle-East and South-East Asia*; Oxford University Press: New York, NY, USA, p. 433.

57. Geritts, A.M.J. (2010). The role of interception in the hydrological cycle. Dissertation at the Water Resources Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, and at the Gabriel Lippmann Research Center, Luxembourg.
58. Horton, (1933). The role of infiltration in the hydrologic cycle. *Trans. Amer. Geophys. Union*, 14, 446-460.
59. Pandey, A. (2016). Society and Environment in Ancient India (Study of Hydrology). *International Journal of Humanities and Social Science Invention*, Vol. 5(2), pp.26-31.
60. Shaw, J. Sutcliffe, J. Lloyd-Smith, L. Schwenninger, J-L. and Chauhan, M. S. (2007). Ancient Irrigation and Buddhist History in Central India: Optically Stimulated Luminescence Dates and Pollen Sequences from the Sanchi Dams. *Asian Perspectives*, Vol. 46, No.1.
61. Angelakis, A.N. and Zheng, X.Y. (2015). Evolution of Water Supply, Sanitation, Wastewater, and Stormwater Technologies Globally. *Water* 2015, 7, 455-463; doi:10.3390/w7020455.
62. Hasan, F. (2011). *Water History for Our Times*. Published by the United Nations Educational, Scientific and Cultural Organization (UNESCO), International Hydrology Programme (IHP), 7, place Fontenoy, 75352 Paris 07 SP, France.
63. Hugo, V. (1982). *Les Misérables*, Trans. Norman Denny. Penguin Classics, New York, 2001.
64. Avvannavar, M.S. and Mani, M. A. (2008). Conceptual model of people's approach to sanitation. *Sci. Total Environ.* Vol. 390, pp. 1-12.
65. Sorcinelli, P. (1998). *Storia sociale dell'acqua. Riti e Culture*. Milano: Mondadori.
66. De Feo, G. and Napoli, RMA. (2007). Historical development of the Augustan Aqueduct in Southern Italy: twenty centuries of works from Serino to Naples. *Water Sci Technol.* Vol. 7: 131–8.
67. Lofrano, G. and Brown, J. (2010). Wastewater management through the ages: A history of mankind. *Science of the Total Environment*, Vol. 408, pp. 5254–5264.
68. Maneglier, H. (1994). *Storia dell'acqua*. Milano: Sugar Co.
69. Tarr, JA. (1985). Historical perspectives on hazardous wastes in the United States. *Waste Manage Res.*; 3:95-113.
70. Viale, G. (2000). *Un mondo usa e getta*. Milano: Feltrinelli.
71. Sori, E. (2001). *La città e i rifiuti — Ecologia urbana dal Medioevo al primo Novecento*. Saggi, Bologna: Il Mulino.
72. Neri Serneri, S. (2007). The construction of the modern city and the management of water resources in Italy, 1880–1920. *J Urban Hist.*, Vol. 33, pp. 813–27.
73. Kenoyer, J. M. (1997). Trade and technology of the Indus Valley: new insights from Harappa, Pakistan. *World Archaeology* 29 (2), 262–280.
74. Kenoyer, J.M. (1991). The Indus valley tradition of Pakistan and Western India. *J. World Prehist.* 5, 331–385.
75. Kenoyer, J.M. (1998). *Ancient Cities of the Indus Valley Civilization*; Oxford University Press/American Institute of Pakistan Studies: Karachi, Pakistan, pp. 1–260.
76. Khan, S. (2014). Sanitation and wastewater technologies in Harappa/Indus valley civilization (ca. 2600–1900 BC). Book Chapter, in 'Evolution of Sanitation and Wastewater Technologies through the Centuries' (Editors: A. N. Angelakis and J. B.

- Rose), IWA Publishing Alliance House, 12 Caxton Street London SW1H 0QS, UK, pp. 25-40.
77. Wolfe, P. (1999). History of wastewater. World of water 2000—the past, present and future. Water World/Water and Wastewater International Supplement to Penn Well Magazines, Tulsa, OH, USA; 1999.
 78. Wright, R. P. (2010). The Ancient Indus: Urbanism, Economy, and Society. Cambridge University Press, New York, 396.
 79. Fardin, H.F. Hollé, A. Gautier, E. Haury, J. (2013). Wastewater management techniques from ancient civilizations to modern ages: Examples from South Asia. *Water Sci. Technol.* 13, 719–726.
 80. Kirk, W. (1975). The role of India in the diffusion of early cultures. *The Geographical Journal* 141 (1), 19–34.
 81. Mate, M. S. (1969). Building in ancient India. *World Archaeology* 1(2), 236–246.
 82. Singh, U. (2008). History of Ancient and Early Medieval India: From the Stone Age to 12th Century. Pearson Education/Dorling Kindersley, New Delhi, 704 p.
 83. Casal, J. M. (1949). Les fouilles de Virapatnam-Arikamedu. *Comptesrendus des séances de l'Académie des Inscriptions et Belles-Lettres*, 93rd years, 2, pp. 142–147.
 84. Begley, V. (1983). Arikamedu reconsidered. *American Journal of Archaeology* 87 (4), 461–481.
 85. Begley, V. (2004). The dating of Arikamedu and its bearing on the archaeology of early historical South India. In: South Indian Horizons (J. L. Chevillard & E. Wilder, eds.). Institut Français de Pondichéry/Ecole Française d'Extrême-Orient, Pondicherry, pp. 513–537.
 86. Bharadwaj, H. C. (1997). Town planning, building and building materials. In: History of Technology in India (A. K. Bag, ed.). Indian National Science Academy, New Delhi, Vol. 1, pp. 498–523.
 87. Nair, K.S. (2004). Role of water in the development of civilization in India—a review of ancient literature, traditional practices and beliefs. *The Basis of Civilization ~ Water Science? (Proceedings of the UNESCO/IAHS/IWI [a symposium held in Rome. December 2003]. IAHS Publ. 286.*
 88. Bagchi, K.S. and Bagchi, S.S. (1991). History of Irrigation in India. Part I: Irrigation in Ancient India (from 2295 BC up to 11th Century). *Irrigation and Power*, pp. 69-76.
 89. Srinivasan, T. M. (1976). Measurement of Rainfall in Ancient India, *IJHS* 11.2, 148-57.
 90. Shaw, J. and Sutcliffe, J. (2003) Water Management, Patronage Networks and Religious Change: New evidence from the Sanchi dam complex and counterparts in Gujarat and Sri Lanka, *South Asian Studies*, 19:1, 73-104, DOI:10.1080/02666030.2003.9628622.
 91. Kielhorn, F. (1906). “Junagadh rock inscription of Rudradaman: the year 72”, *Epigraphica Indica* VIII, pp. 36-49.
 92. Shaw, J. and Sutcliffe, J. (2001) Ancient irrigation works in the Sanchi area: an archaeological and hydrological investigation, *South Asian Studies*, 17:1, 55-75, DOI: 10.1080/02666030.2001.9628592.
 93. Sutcliffe, J. Shaw, J. and Brown, E. (2011). Historical water resources in South Asia: the hydrological background. *Hydrological Sciences Journal*, 56(5): 775–88.

94. Jansen M. (1985). Mohenjo-Daro, city of the Indus Valley, Endeavour, New Series. Volume 9, No. 4, Pergamon Press, Printed in Great Britain, London, UK.
95. Jansen M. (1989). Water supply and sewage disposal at Mohenjo-Daro. *World Archaeology* 21(2), 177 – 192.
96. Majumdar, P.P. and Jain, S.K. (2018). Hydrology in Ancient India: Some Fascinating Facets. *Geophysical Research Abstracts*, EGU General Assembly, Vol. 20, EGU2018-8690.
97. Nair, K.S. (2004). Role of water in the development of civilization in India-a review of ancient literature, traditional practices and beliefs, The basis of Civilization-Water Science? (Proceedings of the UNESCO/IAHS/IWHA, symposium held in Rome December 2003), IAHS Pubi. 286.

GLOSSARY OF TERMS

- Albedo:** The portion of the total incoming radiation that is reflected back to space expressed as a ratio of the reflected to incoming radiation.
- Alkalinity:** A term used to represent the content of carbonates, biocarbonates, hydroxides and occasionally borates, silicates and phosphates in water expressed in ppm (part per million) or mg/lit of equivalent calcium carbonate.
- Arid Zone:** Region or climate lacking sufficient moisture for crop production without irrigation; upper annual limit of precipitation for cool region is 25 cm and for tropical region is 40-50 cm.
- Artesian well:** A well penetrating an artesian aquifer. An artesian aquifer is overlain and underlain by a confining layer so that water in these aquifers occurs under pressure. Boring in this aquifer causes the water to rise due to its own pressure.
- Atmosphere:** The word atmosphere is taken to refer to the gaseous envelop of any heavenly body, and especially that of the earth.
- Boulder:** Largest unit in sedimentary rocks. Soils etc. usually bigger than 10 cm in size.
- Canal:** Artificial water course used for irrigation or inland navigation.
- Capillarity:** The rise of soil water by adhesion and surface Tension forces as a continous film around soil particles and in the capillary spaces.
- Caverns:** Synonymous with cave, though sometimes it implies a cave of large dimensions. A cave is the under ground hollow space in the earth's crust which may be entered from the surface.
- Climatology:** It is a subdivision of meteorology which deals with the average or normal or collective state of the atmosphere over a given area within a specified period of time i.e. it studies the sum (total) of all atomospheric infiuences. Principally temperature, moisture, wind, pressure and evaporation.
- Cloud:** A mass of small water drops or ice crystais formed in the atmosphere due to condensation of water vapour at great height above the land.
- Condensation:** The physical process of transformation from the vapour to the liquid state.
- Convection:** A process of heat transfer within the atmosphere (or within a gas or fluid), which involves the movement of the medium itself.
- Dales:** Open river valleys.
- Delta:** Roughly triangular area of river-transported sediment at the river mouth deposited by decreasing velocity of water. The sediment is constituted mainly of sand, clay, remains of brackish water organisms, debris of plants and animals washed from land. Delta is formed on low lying coastlines.
- Desert:** Almost barren land having arid hot or cool climate, resulting in sparse vegetation. A desert may have a poor grass-land or scrub.

- Drought:** Lack of rainfall so great and long continued as to affect injuriously the plant and animal life of a place and to deplete water supplies both for domestic purposes and for the operation of power plants. Especially in those regions where rainfall is generally sufficient for such purposes. The term has different connotations in various parts of world e.g. In Bali a period of 6 days without rain is drought. In USA a drought is defined as a period of 21 days or more when the rainfall is 30% or less of the average for the time and place. In parts of Libya, droughts are recognized only after two years without rain.
- Ecology:** Science which deals with interrelations of organisms and their environment.
- Environment:** Sum total of all external conditions influencing the existence or development of an organism or a community.
- Erosion:** Wearing away of land surfaces or detachment and movement of soil, rock etc. by flowing water, wind, ice, gravity etc.
- Evaporation:** The process by which the water is changed from the liquid state to a gaseous state below the boiling point through the transfer of heat energy.
- Evapotranspiration:** Combined loss of moisture from soil by evaporation and from vegetation by transpiration from a given area in a specified time period.
- Flood:** The flow of water which causes submergence of land not usually covered with water, or an increase in the depth of water on land already partially submerged, through a temporary rise in river lake or sea levels.
- Flood Plain:** The low-lying land that borders a river and is subjected to periodic flooding. It is composed of deposits of sediment (alluvium) of variable thickness laid down by the flood waters above the rock floor and is bounded by low bluffs.
- Fog:** Droplets of water suspended in the lower layers of the atmosphere resulting from the condensation of water vapour around nuclei of floating dust or smoke particles. A visibility of less than 1 Km is the internationally recognized definition of fog.
- Frigid Zone:** A general term for Arctic- Antarctic type climates or for areas where the surface is snow covered for a large part of the year and where the sub soil is permanently frozen.
- Frost:** A weather condition that occurs when the air temperature is at or below 0°C. Moisture on the surface of the ground and objects freezes to form an icy deposit.
- Geomorphology:** The study and interpretation of the origins and development of land forms on the earth's surface.
- Glacier:** A mass of ice that moves under the influence of gravity along a confined course away from its source area. It is formed by the accumulation and compaction of snow, which is transformed to firm and ultimately to glacier ice.

- Gravel:** A deposit of unconsolidated material ranging in size from 2 to 60 mm. The particles are usually water worn and hence rounded, and are derived from more than one type of rock.
- Ground Water:** Water that is contained in the soil and underlying rock. Ground Water may be derived from rain water that has percolated down or from water that was trapped within the rock during its formation.
- Humidity:** The amount of water vapour present in the atmosphere.
- Hurricane:** A wind that has a velocity in excess of 32.7 m per second. It is tropical cyclone occurring around the Caribbean Sea and Gulf of Mexico.
- Hydrologic Cycle:** The cyclic movement of water between the atmosphere, the land and the sea. Water is released into the atmosphere as water vapour through evapotranspiration. After condensation within the atmosphere to form clouds it returns to the land and to its water bodies as precipitation. This water may runoff the land in rivers streams into lakes and the oceans or move under ground as ground water. Water keeps on moving continuously among above facets of hydrological cycle.
- Hydrology:** The study of water on the earth. Including its chemical and physical properties, occurrence, distribution, and circulation on the surface and below the ground surface.
- Infiltration:** The seepage of water into the soil. The maximum rate at which rainfall can be absorbed by a soil in a given condition is known as infiltration capacity.
- Insolation:** The radiant energy that reaches the surface of the earth from the sun.
- Interception:** The capture of drops of rain by the leaves, branches, and stems of plants. The interception of the rainfall by the vegetation cover prevents some of its from reaching the ground.
- Ionosphere:** The part of earth's atmosphere extending upwards above the stratopause from an altitude of about 60 km.
- Meander:** A pronounced curve or loop in the course of a river channel.
- Meteorology:** The scientific study of the atmosphere and the physical processes at work within it including pressure wind, temperature, clouds, pressure etc.
- Mist:** A reduction of visibility within the lower atmosphere to 1-12 km caused by condensation producing water droplets within i.e lower layers of the atmosphere.
- Monsoon:** A large-scale seasonal reversal of winds pressure and rainfall in the tropics. The largest and best developed monsoonal area in the world is South East-Asia.
- Perennial river:** Rivers flowing throughout the year are called perennial rivers.
- Pervious Strata:** A rock system through which water can pass freely as a result of joints, bedding planes, cracks and fissures in the rock.
- Physiography:** The study of the surface forms of a region. The word has changed its meaning over the years from covering the whole of physical geography including geomorphology.

- Plateaus:** An extensive elevated area of relatively flat land. Widespread movements of the earth's crust may result in vertical warping, which produces plateaus and rift valleys divided by faults.
- Pore space:** The amount of space between the mineral grains of rock, soil or sediment.
- Precipitation:** The particles of water or ice that form within clouds and fall towards the earth's surface.
- Rain gauge:** An instrument designed to measure rainfall. In its simplest form it consists of a funnel fitted into a collecting vessel. Any rain collected in the vessel over a set period of time is measured in a specially graduated measuring cylinder, an exercise that occurs twice daily at most meteorological stations.
- Rain Shadow:** An area of low rainfall in the lee of hills or mountain ranges.
- Reservoir:** A storage area for water usually a river valley that has been dammed to retain water for one or more purposes, such as irrigation, industrial use, water supply, hydro-electric power or recreation.
- Rills:** Erosion of the soil surface by shallow short-lived channels. These small channels are called rills.
- Saline soil:** A group of intra zonal soils that contain high concentrations of salts such as common salt. They often occur in semiarid and arid areas where there is strong evaporation.
- Semi Arid:** The climate of the areas between desert and tropical grassland. The mean annual rainfall ranges between 100 mm to 300 mm.
- Sluice:** Channel or conduit to drain off surplus water at high velocity or for passing debris. Also, to allow a water flow at high velocity for ejecting debris.
- Snow:** A form of precipitation consisting of crystals of ice. It is produced when condensation takes place at a temperature below freezing point.
- Spillway:** An open or closed passage cut in soil or rock. When a dam is full, any further incoming water flows over or through the spillway without any damage to the structure.
- Stratosphere:** The layer of the atmosphere that lies between the tropopause, at an average altitude of about 8 km, and the stratopause, at about 50 km.
- Temperate Region:** The division of the world based on temperature lying between the torrid and frigid zones, and meaning an area where there are no extremes of temperature.
- Termite mound:** The nest made from mud or plant debris, that, houses a colony of termites (Tropical type of ant),
- Topography:** The surface features (i.e. land forms) of an area of land or sea bed.
- Tornado:** A violently rotating storm in which winds whirl around a small area of extremely low pressure.
- Torrid:** One of the three divisions of the world based on temperature. It is the zone lying between the tropics.
- Troposphere:** The lowest layer of the earth's atmosphere.
- Turbidity:** The muddiness of water resulting from suspended sediment.

- Turbulence:** An irregular disturbed flow of fluid e.g. water, air).
- Water falls:** A steep cliff like section of a river channel down which water falls vertically.
- Water lift:** Any mechanism (generally lever principle) to raise the water from a source of lower datum to obtain water for useful purposes.
- Water oozing:** Water seeping out of the ground and wetting it without perceptible flow.
- Water Table:** The upper surface of the zone of saturated rocks i.e. rocks in which all voids are filled with water.
- Water Treatment:** Any method used to obtain potable water from a contaminated source of water.
- Water uptake:** Water ascends upward through the capillarity of soil and root system of plants. The utilization of water by plants is termed as water uptake.
- Water Veins:** The underground structures through which the water moves through the soil. These are passages formed by the interconnections of pore spaces of soil. In ancient Indian literature these have been said to be resembling the veins in the human body.

STUDY TEAM FOR FIRST EDITION

Satish Chandra	:	Director
T. M. Tripathi	:	Scientist-B
V. K. Srivastava	:	Documentation staff

EDITORS OF SECOND EDITION

Sharad Kumar Jain	:	Director
A. K. Lohani	:	Scientist-G
S. D. Khobragade	:	Scientist-F
P. K. Singh	:	Scientist-D
Md. Furqan Ullah	:	A. L. I. O.
Charu Pandey	:	L. I. A.